Structure Functions at Low Q^2

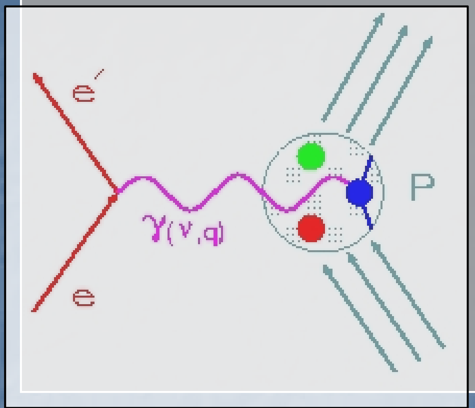
Jefferson Lab

Outline

- ✓ Deep-Inelastic Scattering
- ✓ Structure Functions
- ✓ Experimental Status SFs
- ✓ F_2 Sensitivity on R
- ✓ Power Corrections (Target Mass Correction)
- ✓ Power Corrections (Twist Effects)
- ✓ Physics at Low Q^2
- ✓ Nuclear Effects in F_2 and R
- ✓ Results from Experiments
- ✓ Summary

Deep-Inelastic Scattering (1)

The differential cross section for inclusive lepton nucleon scattering can be expressed as a function of the leptonic tensor $L^{\mu\nu}$ and the hadronic tensor $W_{\mu\nu}$, which describe respectively the electron and the hadron vertex.



With α the fine structure constant

$$\frac{d\sigma}{d\Omega dE'} = \frac{\alpha^2}{Q^4}\frac{E'}{E}L_{\mu\nu}W^{\mu\nu}$$

Where: E & E' initial and scattered energy of the lepton and Q^2 is the negative squared mass of the virtual photon. Θ is the angle between the initial and final directions of the lepton.

$$Q^2 \equiv -q^2 = 4EE'\sin^2\left(\frac{\theta}{2}\right)$$

The leptonic tensor is completely calculable from QED. The hadronic tensor describes transitions to all possible final states.

Using constraints from Lorentz and gauge invariance, the hadronic tensor can be decomposed into two independent structures:

The general expression for the differential cross section written in the laboratory as:

The leptonic tensor averaged over initial spins is given by

$$W^{\mu\nu} = W_1(\nu,Q^2)\left(\frac{q^\mu q^\nu}{q^2} - g^{\mu\nu}\right) + \frac{W_2(\nu,Q^2)}{M^2}\left(p^\mu + \frac{p\cdot q}{q^2}q^\mu\right)\left(p^\nu + \frac{p\cdot q}{q^2}q^\nu\right)$$

Where k and k' are the initial and final electron momenta, respectively.

Deep-Inelastic Scattering (2)

Where the Mott cross section σ_{Mott} is given by:

$$\sigma_{Mott} = \frac{\alpha^2 \cos^2\left(\frac{\theta}{2}\right)}{4E^2 \sin^4\left(\frac{\theta}{2}\right)}$$

And ν is the energy transfer of the lepton to the target rest frame:

$$\nu = E - E'$$

Mott cross section σ_{Mott} represents the cross section for elastic electron scattering from a spinless point charge.

The two structure functions W_1 and W_2 contain the information about the structure of the nucleon in the final state, and have to be determined by experiment.

Usually the two structure functions W1 and W2 are expressed in terms of the dimensionless functions F_1 and F_2 as:

$$F_1(x, Q^2) = MW_1(\nu, Q^2)$$
$$F_2(x, Q^2) = \nu W_2(\nu, Q^2)$$

Structure Functions (1)

In the quark-parton model the F_1 and F_2 structure functions are given in terms of quark and antiquark distribution functions.

$$F_2(x) = 2xF_1(x) = x\sum_q e_q^2\left(q(x)+\overline{q}(x)\right)$$

Where q(x) is the interpreted as the probability to find a quark of flavor q in the nucleon with momentum fraction x.

$$x = \frac{Q^2}{2M\nu}$$

x can be interpreted as the fraction of the nucleon momentum carried by the struck parton.

$$\frac{d^2\sigma}{d\Omega\, dE'} = \sigma_{Mott}\left[\frac{1}{\nu}F_2\left(\nu, Q^2\right) + \frac{2}{M}F_1\left(\nu, Q^2\right)\tan^2\frac{\theta}{2}\right]$$

By the analogy to the expression for absorption of real photons the differential cross section can be expressed in terms of longitudinal (σ_L) and transverse (σ_T) virtual-photon cross sections as

$$\frac{d^2\sigma}{d\Omega\, dE'} = \Gamma\left[\sigma_T\left(x, Q^2\right) + \varepsilon\sigma_L\left(x, Q^2\right)\right]$$

Structure Functions (2)

$$\frac{d^2\sigma}{d\Omega dE'} = \Gamma\left[\sigma_T\left(x,Q^2\right) + \varepsilon\sigma_L\left(x,Q^2\right)\right]$$

Where Γ is the transverse virtual photon flux

The variable ε represents the virtual photon polarization parameter.

$$\Gamma = \frac{\alpha K}{2\pi^2 Q^2}\frac{E'}{E}\frac{1}{1-\varepsilon}$$

$$K = \frac{2M\nu - Q^2}{2M}$$

$$\varepsilon = \left[1 + 2\left(1 + \frac{Q^2}{4M^2x^2}\right)\tan^2\frac{\theta}{2}\right]^{-1}$$

$0 \leq \varepsilon \leq 1$

In terms of σ_T and σ_L, the structure functions F_1 and F_2 can be written as:

$$F_1\left(x,Q^2\right) = \frac{MK}{4\pi^2\alpha}\ \sigma_T\left(x,Q^2\right)$$

$$F_2\left(x,Q^2\right) = \frac{\nu K\left(\sigma_T\left(x,Q^2\right) + \sigma_L\left(x,Q^2\right)\right)}{4\pi^2\alpha\left(1 + \nu^2/Q^2\right)}$$

F_1 is therefore a purely transverse structure function

It is useful further to define a purely longitudinal structure function F_L

$$F_L\left(x,Q^2\right) = \left(1 + \frac{Q^2}{\nu^2}\right)F_2\left(x,Q^2\right) - 2xF_1\left(x,Q^2\right)$$

Structure Functions (3)

The Ratio of longitudinal to transverse cross sections can be expressed as

$$R \equiv \frac{\sigma_L}{\sigma_T} = \frac{F_2}{2xF_1}\left(1 + \frac{4M^2x^2}{Q^2}\right) - 1 \quad \text{OR} \quad R = \frac{F_L}{2xF_1}$$

Using the Ratio R, the F2 structure function can be extracted from the measured differential cross sections according to

$$F_2\left(x, Q^2\right) = \frac{\sigma}{\sigma_{Mott}} \nu\varepsilon \frac{(1+R)}{(1+\varepsilon R)}$$

Knowledge of R is therefore a prerequisite for extracting information on F2 (or F1) from inclusive electron scattering cross sections

Two methods of Getting R

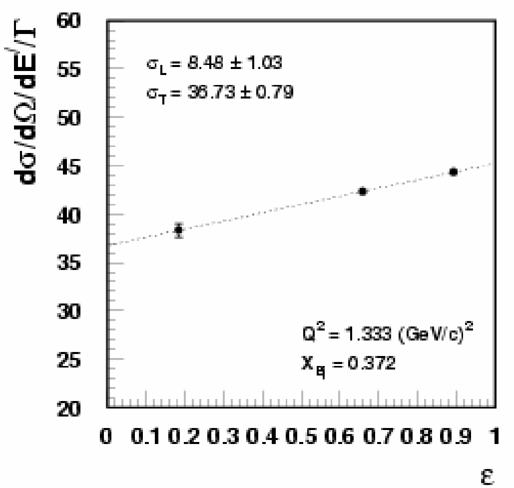
1st Method

Rosenbluth Separation

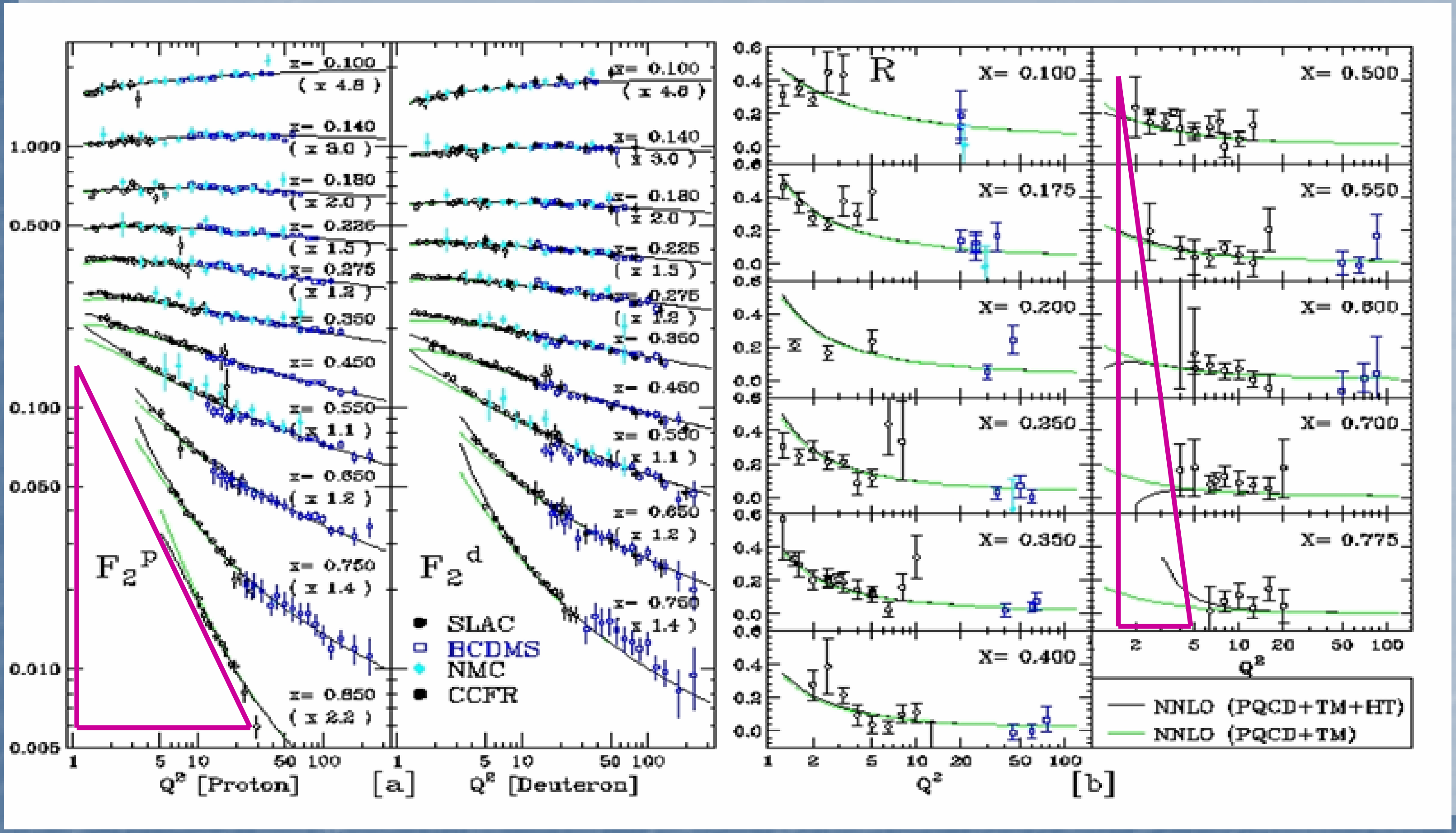
Requirements:

The same x, Q^2 but different ε.

$$\frac{d^2\sigma}{d\Omega dE'} = \Gamma(\sigma_T + \varepsilon\sigma_L)$$

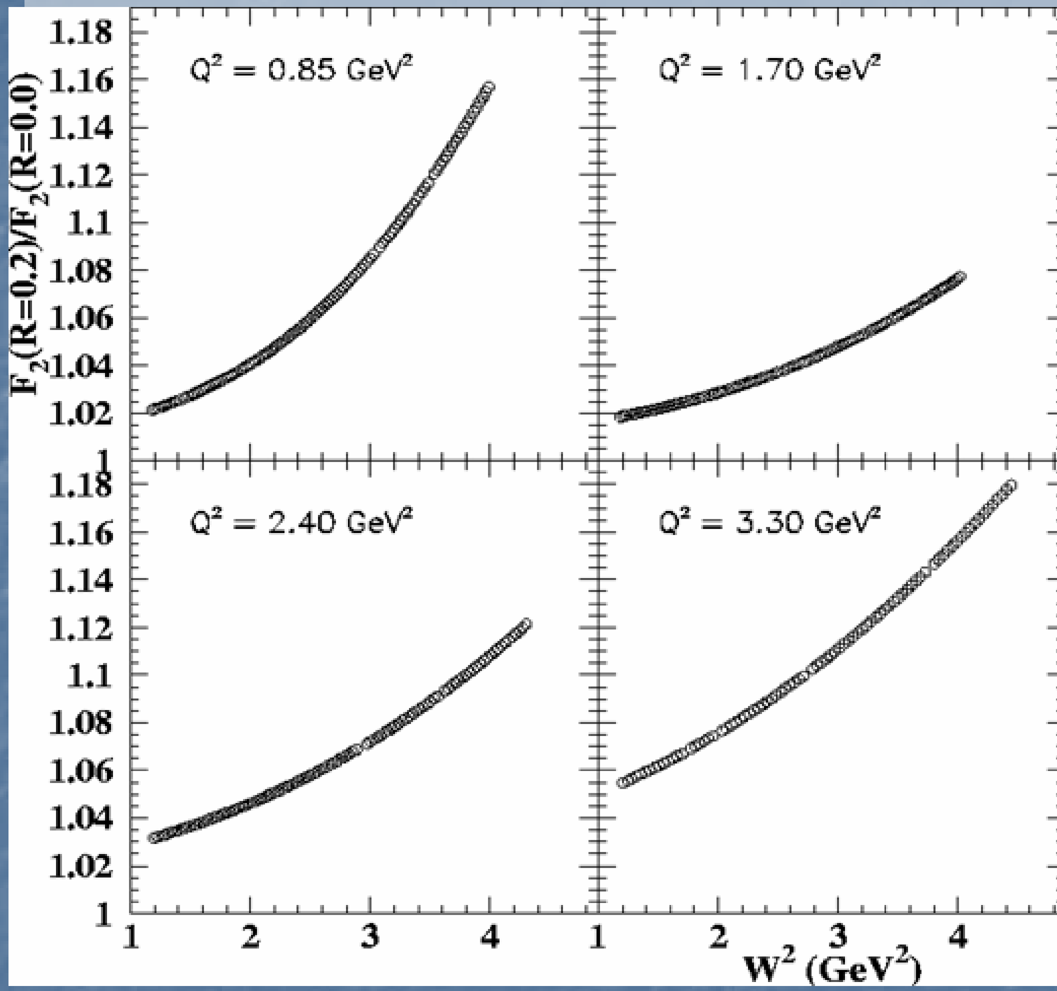


Experimental Status of Unpolarized SFs



- ➔ F_2 well measured - responsible for much understanding of proton structure
- ➔ Nonetheless, large *x*, low Q^2 region is sparse
- ➔ R (F_L), is not at all so well measured (especially large *x*, low Q^2)
- ➔ Situation is worse for nuclei
- ➔ *If R nonzero*, NEED longitudinal / transverse (L/T) separations to extract F_2

F_2 Sensitivity on R



At W^2 = 4 GeV² and Q^2 < 1 GeV², F_2 will vary by 15% depending on the choice of R = 0 or R = 0.2. At higher Q^2, this can be as much as 20%.

Power Corrections (Target Mass Correction)

Additional corrections exist at low Q^2 which are needed in order to fully account for the scaling violations. These corrections are called power corrections and have a form $1/(Q^2)^n$. The operator product expansion (OPE) is generally used to discuss these power corrections within the framework of QCD.

One type of power corrections to the structure function are target mass corrections, which arise from the non-vanishing mass M of the target hadron. QCD predictions have been derived under the assumption that the nucleon mass can be neglected when the energy transfer is high, which corresponds to high Q^2. However, at low Q^2 this is no longer the case and correction terms have to be included.

By applying the target mass corrections directly to the structure functions $F_i(x,Q^2)$ can be related to corrected structure functions $F_i(\xi,Q^2)$. These corrected structure functions satisfy the DGLAP equations and depend on the Nachtmann scaling variable ξ, which is defined as

$$\xi = \frac{2x}{1+\sqrt{1+4M^2x^2/Q^2}}$$

It is to be noticed that $\xi \rightarrow x$ for high Q^2. This is consistent with the QPM, which predicts that x is the correct scaling variable at large Q^2.

Power Corrections (Target Mass Correction)

When M^2x^2/Q^2 terms are negligible, F2(x) can be constructed from the PDFs, with Q^2 evolution given by pQCD.

target mass (TMC) - kinematic corrections due to binding of partons in the nucleon.

(x is no longer the longitudinal momentum fraction carried by struck parton).

TM formalism considered due to H. Georgi and D. Politzer

$$F_2^{TM}(x, Q^2) = \frac{x}{k^3}\frac{F_2^{QCD}(\xi, Q^2)}{\xi^2} + \frac{6M^2x^3}{Q^2k^4}I_1 + \frac{12M^4x^4}{Q^4k^5}I_2$$

$$k = \left(1 + \frac{4x^2M^2}{Q^2}\right)^{1/2}, \quad \xi = \frac{2x}{1+k}$$

$$I_1 = \int_\xi^1 du \frac{F_2^{QCD}(u, Q^2)}{u^2}, \quad I_2 = \int_\xi^1 du \int_u^1 dv \frac{F_2^{QCD}(v, Q^2)}{v^2}$$

Power Corrections (Twist Effects)

According to the OPE the structure functions can be expanded in powers of $1/Q^2$

$$F_2(x,Q^2) = \sum_{n=0}^{\infty} \frac{C_n(x,Q^2)}{\left(Q^2\right)^n} = C_0(x,Q^2) + \frac{C_1(x,Q^2)}{Q^2} + \frac{C_2(x,Q^2)}{Q^4} + \ldots\ldots\ldots\ldots$$

Where the functions $C_n(x,Q^2)$ weakly depends (i.e. logarithmically on Q^2. The various terms in this expansion are referred to as leading ($n=0$) and higher ($n\geq1$) twists.

The twist number (t) is defined in such a way that the leading one is equal to two and higher ones correspond to the consecutive even integers.

Thus the right-hand side of the equation corresponds to the leading twist contribution to F_2

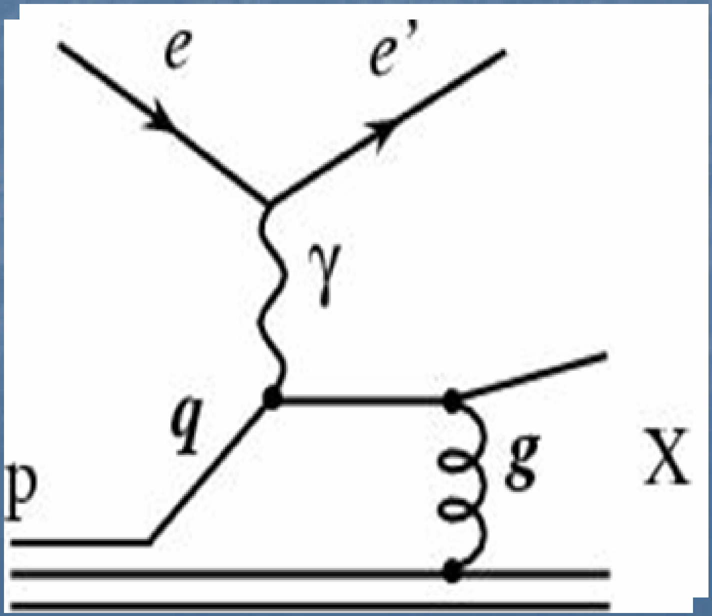
$$F_2(x) = 2xF_1(x) = x\sum_q e_q^2\left(q(x)+\bar{q}(x)\right)$$

Power Corrections (Twist Effects)

The higher twist operators correspond to interactions between the struck quark and the spectator quarks:

$$F_2(x,Q^2) = \sum_{n=0}^{\infty} \frac{C_n(x,Q^2)}{\left(Q^2\right)^n} = C_0(x,Q^2) + \underbrace{\frac{C_1(x,Q^2)}{Q^2} + \frac{C_2(x,Q^2)}{Q^4} + \ldots\ldots\ldots\ldots}$$

The size of these terms cannot be easily calculated, since they depend on the unknown wave function of the bound-state quarks.



F_2 is usually parametrized as:

$$F\left(x,Q^2\right) = F^{LT}\left(x,Q^2\right)\left(1 + \frac{C(x)}{Q^2} + \ldots\right)$$

C(x) characterizes the strength of the twist-four term

Physics at Low Q² (Overview)

In the region of high Q^2 the results of DIS measurements are interpreted in terms of partons (quark and gluons). The theoretical framework is provided in this case by the QCD improved parton model. The description fails when Q^2 becomes of the order of 1* $(GeV/c)^2$, where non-perturbative effects become important (non-pQCD), which are still not fully understood.

$$W^{\mu\nu} = \frac{F_1(x,Q^2)}{M}\left(-g_{\mu\nu} + \frac{q^\mu q^\nu}{q^2}\right) + \frac{F_2(x,Q^2)}{M(p\cdot q)}\left(p^\mu - \frac{p\cdot q}{q^2}q^\mu\right)\left(p^\nu - \frac{p\cdot q}{q^2}q^\nu\right)$$

This equation can be rearranged in the form

$$W^{\mu\nu} = -\frac{F_1(x,Q^2)}{M}g^{\mu\nu} + \frac{F_2(x,Q^2)}{M(p\cdot q)}p^\mu p^\nu + \left(\frac{F_1(x,Q^2)}{M} + \frac{F_2(x,Q^2)}{M}\frac{p\cdot q}{q^2}\right)\frac{q^\mu q^\nu}{q^2} - \frac{F_2}{M}\frac{p^\mu q^\nu + p^\nu q^\mu}{q^2}$$

The singularities for $Q^2 \rightarrow 0$ (third and fourth terms cannot be real, as otherwise $W^{\mu\nu} \rightarrow \infty$.

In particular, electromagnetic current conservation requires that $q^\mu W_{\mu\nu} = q^\nu W_{\mu\nu} = 0$, where $W_{\mu\nu}$ is the electromagnetic hadronic tensor.

Therefore, the structure functions should obey the following relations in the limit $Q^2 \rightarrow 0$:

Physics at Low Q² (Overview)

$$W^{\mu\nu} = -\frac{F_1(x,Q^2)}{M} g^{\mu\nu} + \frac{F_2(x,Q^2)}{M(p\cdot q)} p^\mu p^\nu$$
$$+\left(\frac{F_1(x,Q^2)}{M} + \frac{F_2(x,Q^2)}{M}\frac{p\cdot q}{q^2}\right)\frac{q^\mu q^\nu}{q^2}$$
$$-\frac{F_2}{M}\frac{p^\mu q^\nu + p^\nu q^\mu}{q^2}$$

The singularities for $Q^2 \rightarrow 0$ (third and fourth terms cannot be real, as otherwise $W^{\mu\nu} \rightarrow \infty$.

In particular, electromagnetic current conservation requires that $q^\mu W_{\mu\nu} = q^\nu W_{\mu\nu} = 0$, where $W_{\mu\nu}$ is the electromagnetic hadronic tensor.

Therefore, the structure functions should obey the following relations in the limit $Q^2 \rightarrow 0$:

at $Q^2 \rightarrow 0$:

$$F_2 = O(Q^2)$$

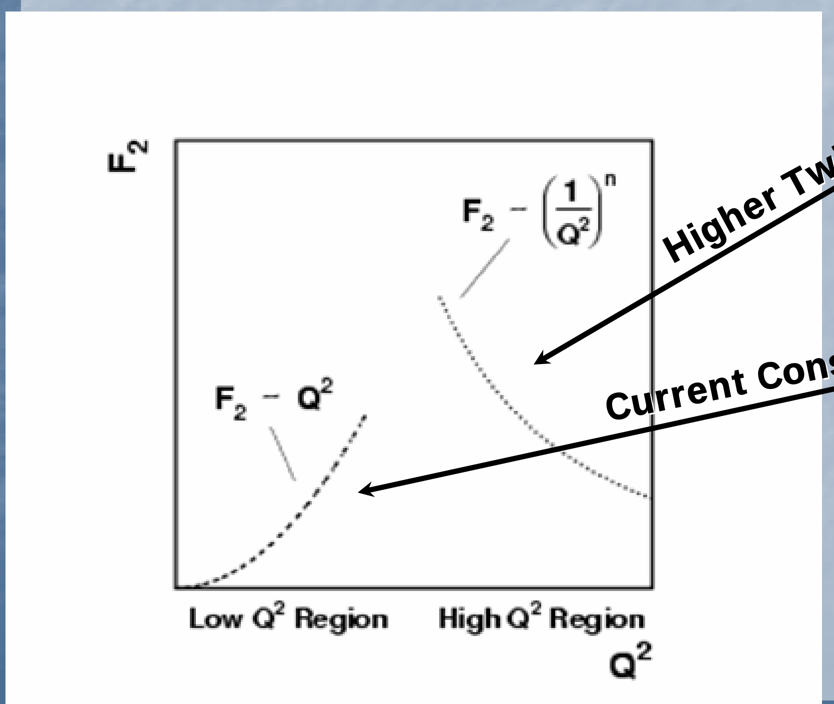
$$\frac{F_1}{M} + \frac{F_2}{M}\frac{p\cdot q}{q^2} = O(Q^2)$$

Thus, the structure function F_2 must !!! Vanish in the limit $Q^2 \rightarrow 0$.

Physics at Low Q² (Overview)

So, what do we have ....

$$F_2(x,Q^2) = \sum_{n=0}^{\infty} \frac{C_n(x,Q^2)}{\left(Q^2\right)^n} = C_0(x,Q^2) + \frac{C_1(x,Q^2)}{Q^2} + \frac{C_2(x,Q^2)}{Q^4} + \ldots\ldots\ldots\ldots$$



Higher Twist

Current Conservation

at $Q^2 \to 0$:

$$F_2 = O(Q^2)$$

$$\frac{F_1}{M} + \frac{F_2}{M}\ \frac{p\cdot q}{q^2} = O(Q^2)$$

Physics at Low Q^2 (Overview)

$$R\left(x,Q^2\right)=\frac{\sigma_L}{\sigma_T}=\frac{\left(1+Q^2/\nu^2\right)F_2}{2xF_1}=\left(1+Q^2/\nu^2\right)\left(1-\mathrm{O}\left(Q^2\right)/F_1\right)-1=\mathrm{O}\left(Q^2\right)$$

- ☺ $F_2(x,Q^2) \to Q^2$ as $Q^2 \to 0$
- ☺ $F_L(x,Q^2) \to Q^4$ as $Q^2 \to 0$
- ☺ $R(x,Q^2) = \sigma_L/\sigma_T \to Q^2$ as $Q^2 \to 0$
- ☺ $\sigma^{\gamma p} = \sigma_T + \varepsilon\sigma_L \to \sigma_T$ as $Q^2 \to 0$

Physics at Low Q² (Overview)

So, we know

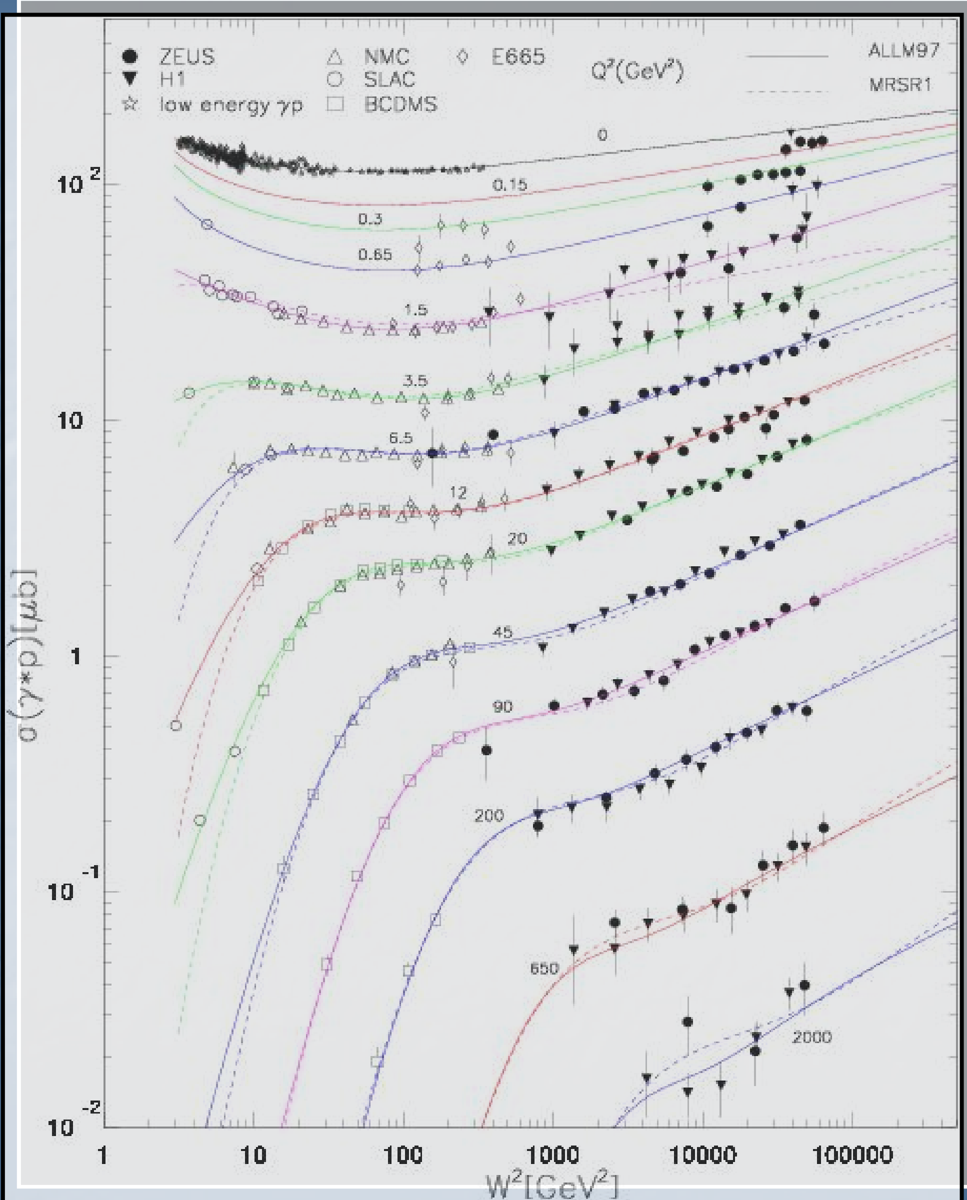
1. the answers at Q²=0.
2. Behavior of structure functions at moderate Q²
3. Effects at low Q²….

Does it mean that the 'life' is easy at low Q² ……….

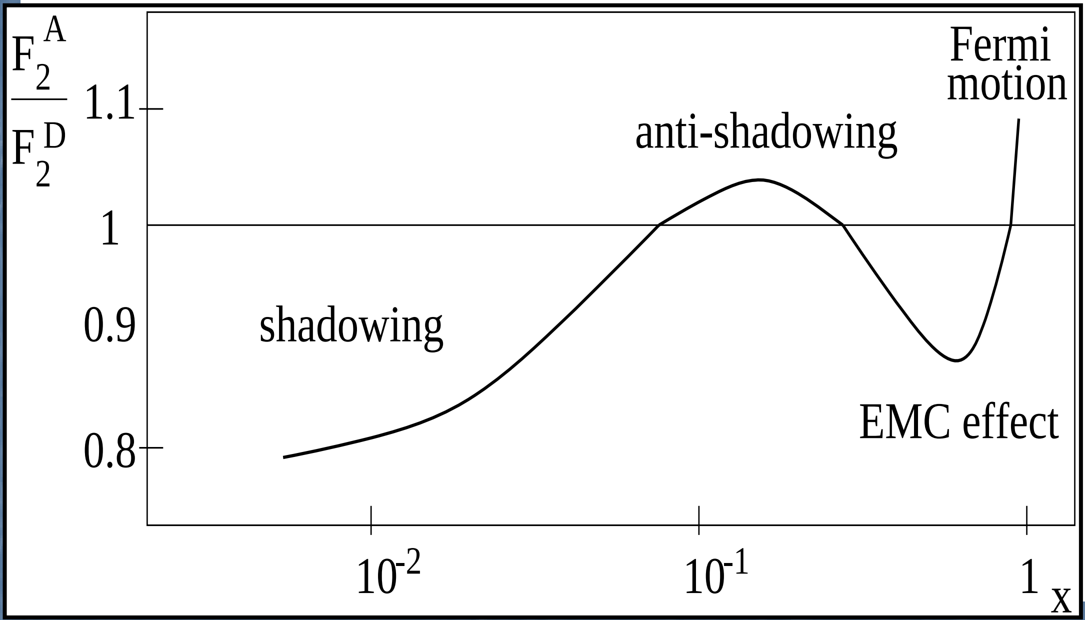
WHY NOT ???

$$\sigma_{tot}\left(\gamma^{*},p\right)\equiv\sigma_L+\sigma_T=$$

$$=\frac{4\pi\alpha^2}{Q^2(1-x)}\frac{Q^2+4m^2x^2}{Q^2}F_2\left(W^2,Q^2\right)$$



Nuclear Effects in F_2 and R



x < 0.05-0.1 **Shadowing**

x ≈ 0.1-0.2 **Anti-Shadowing**

0.2-0.3 < x < 0.8 **EMC Effect**

x > 0.8 **Fermi Motion**

$$\frac{\sigma_A}{\sigma_D} = \frac{F_2^A (1+\varepsilon R_A)(1+R_D)}{F_2^D (1+R_A)(1+\varepsilon R_D)}$$

$$\frac{\sigma_A}{\sigma_D} \underset{\mathbf{IF}}{=} \frac{F_2^A}{F_2^D}$$

$$R = \frac{\sigma_L}{\sigma_T}$$

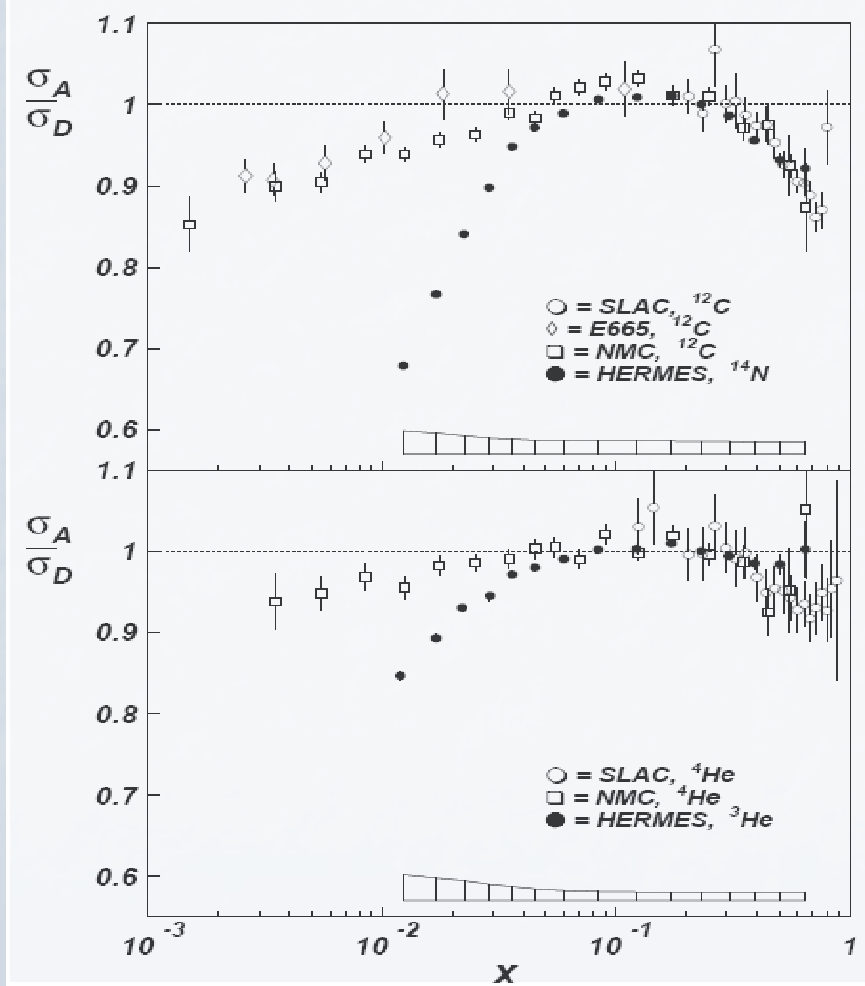
$$\underbrace{}_{\varepsilon=1 \text{ or } R^A=R^D}$$

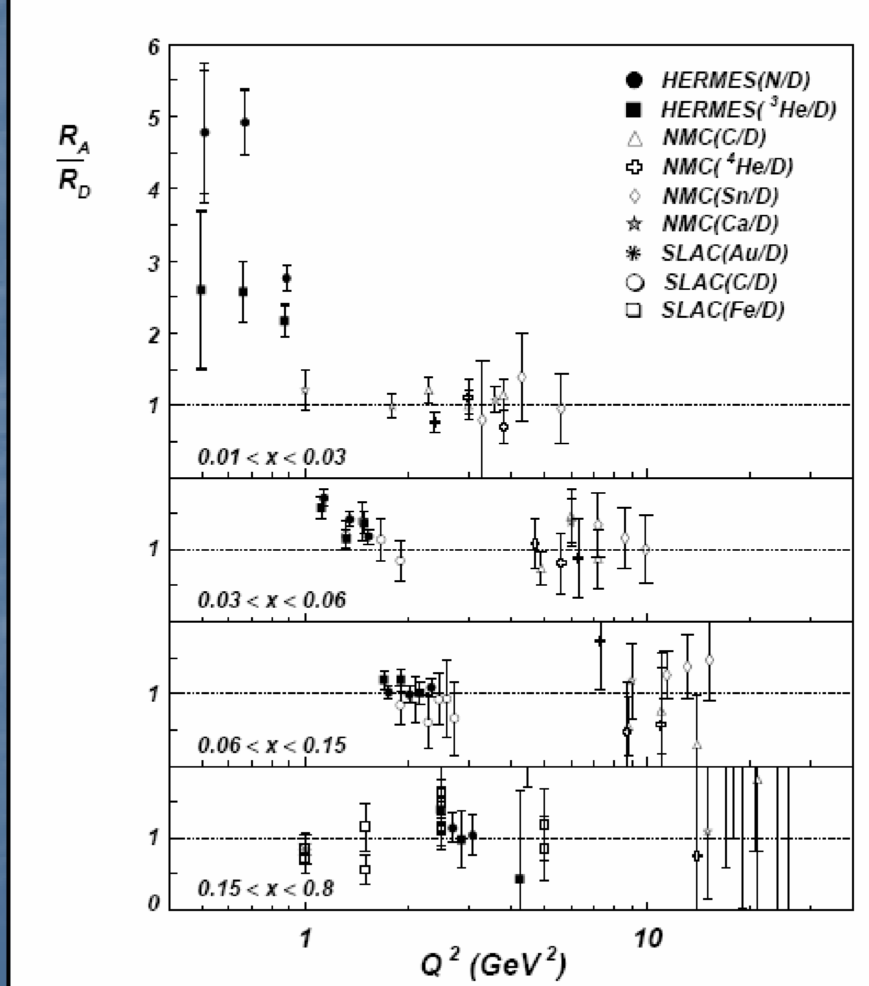
A – dependence of R at low Q² ?

$\varepsilon \approx 1$ (for high Energy) virtual photon polarization parameter

Nuclear Effects in F_2 and R

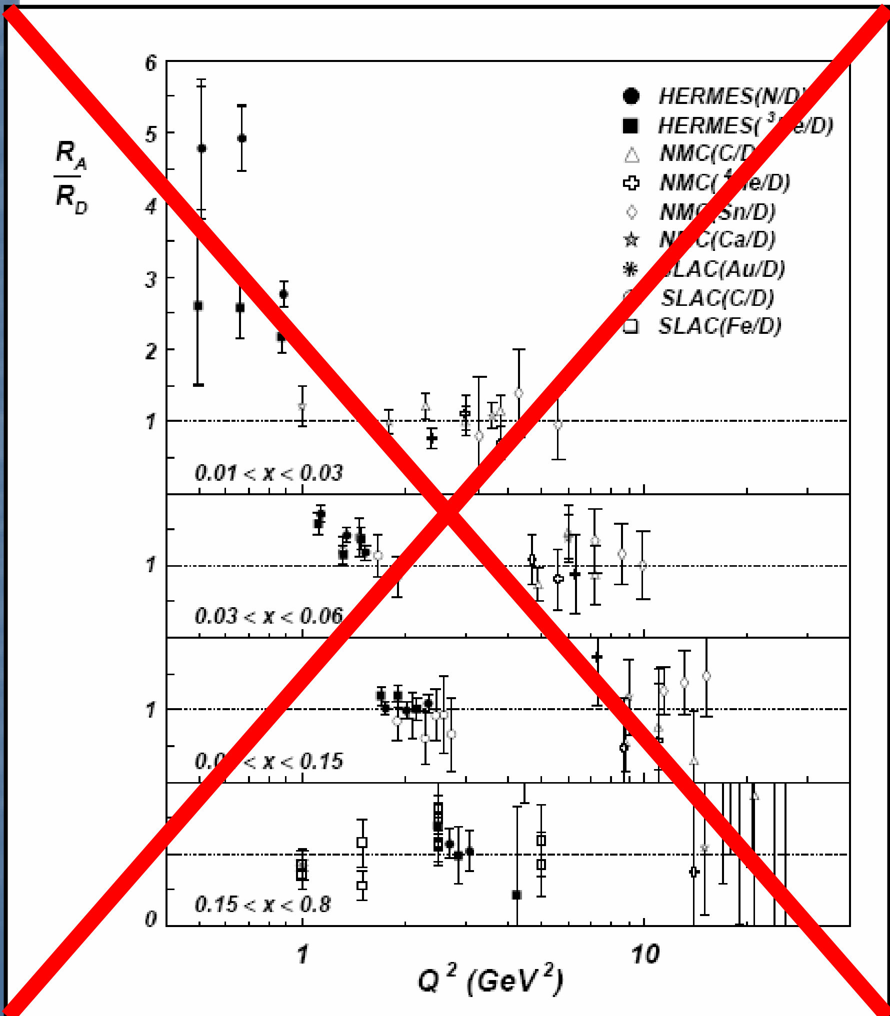
Old results from Hermes Experiment

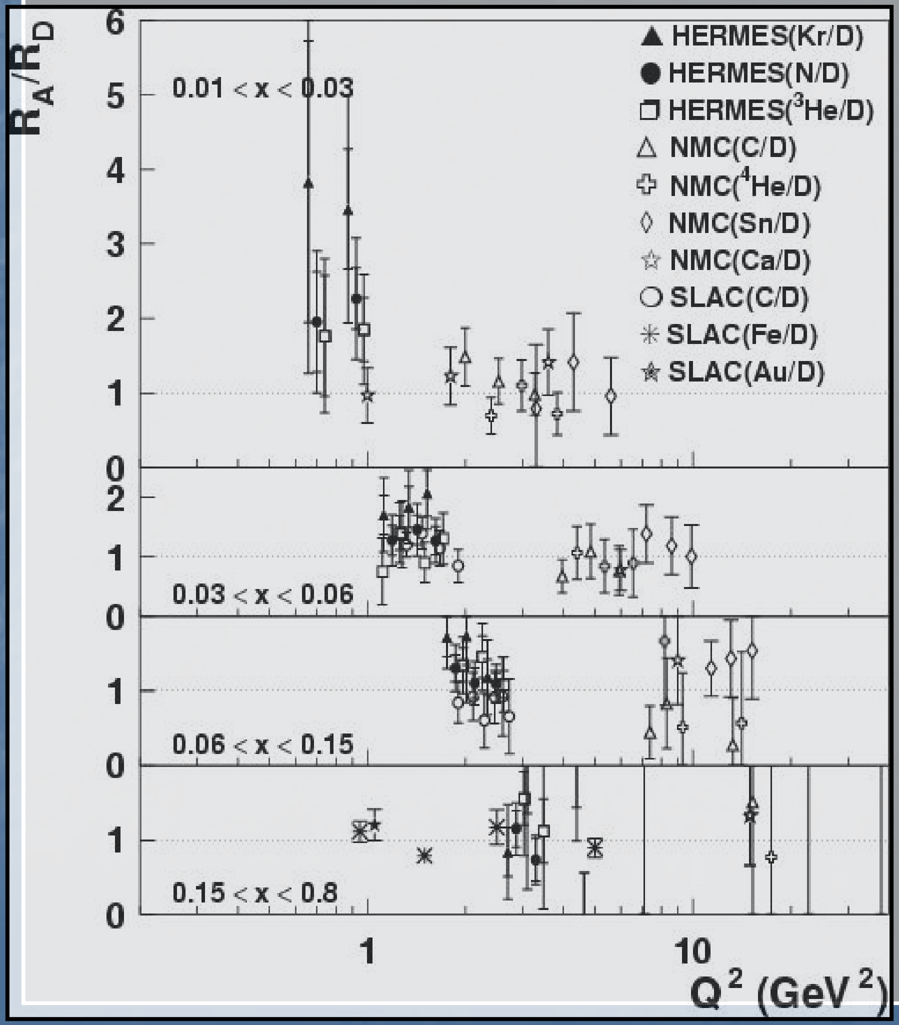




Nuclear Effects in F_2 and R

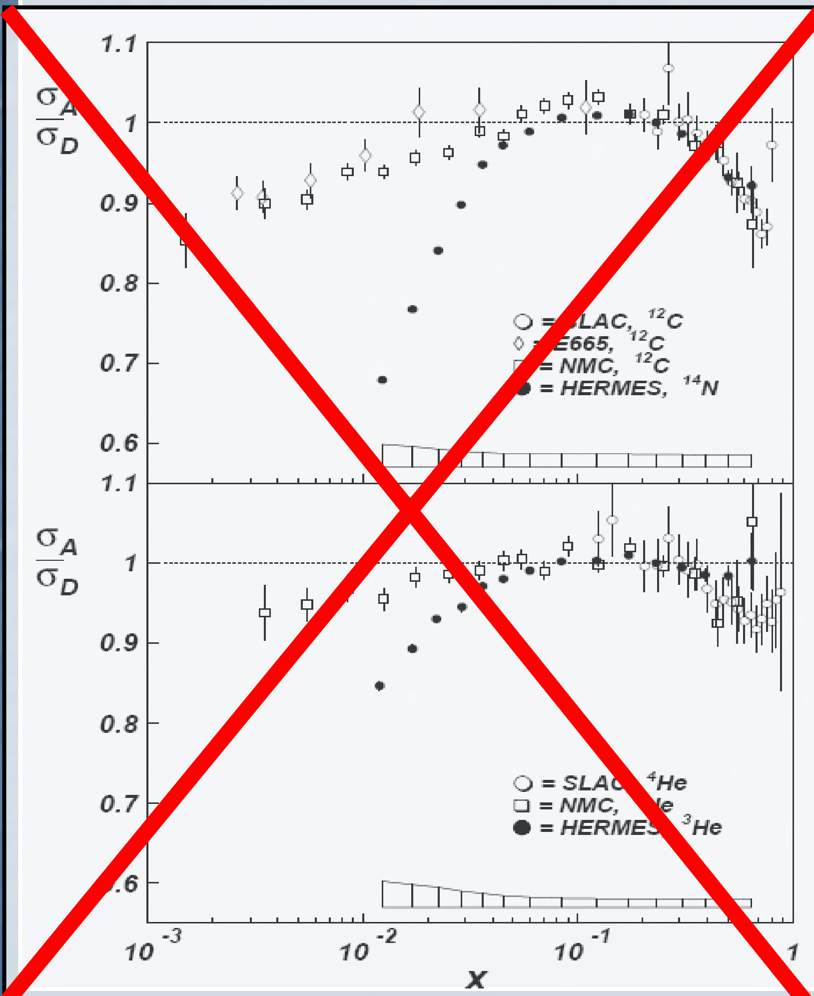
Experimentally, possible nuclear modifications of the transverse-longitudinal ratio R(x,Q2) have been studied by the HERMES collaboration ….

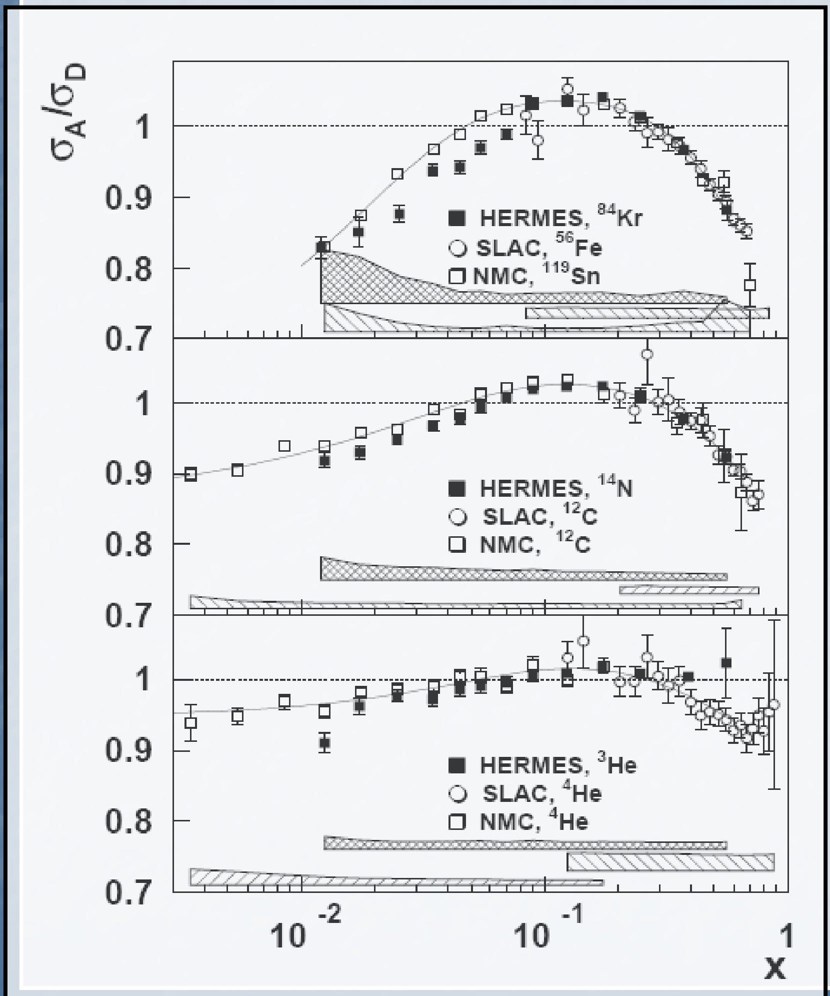




Nuclear Effects in F_2 and R

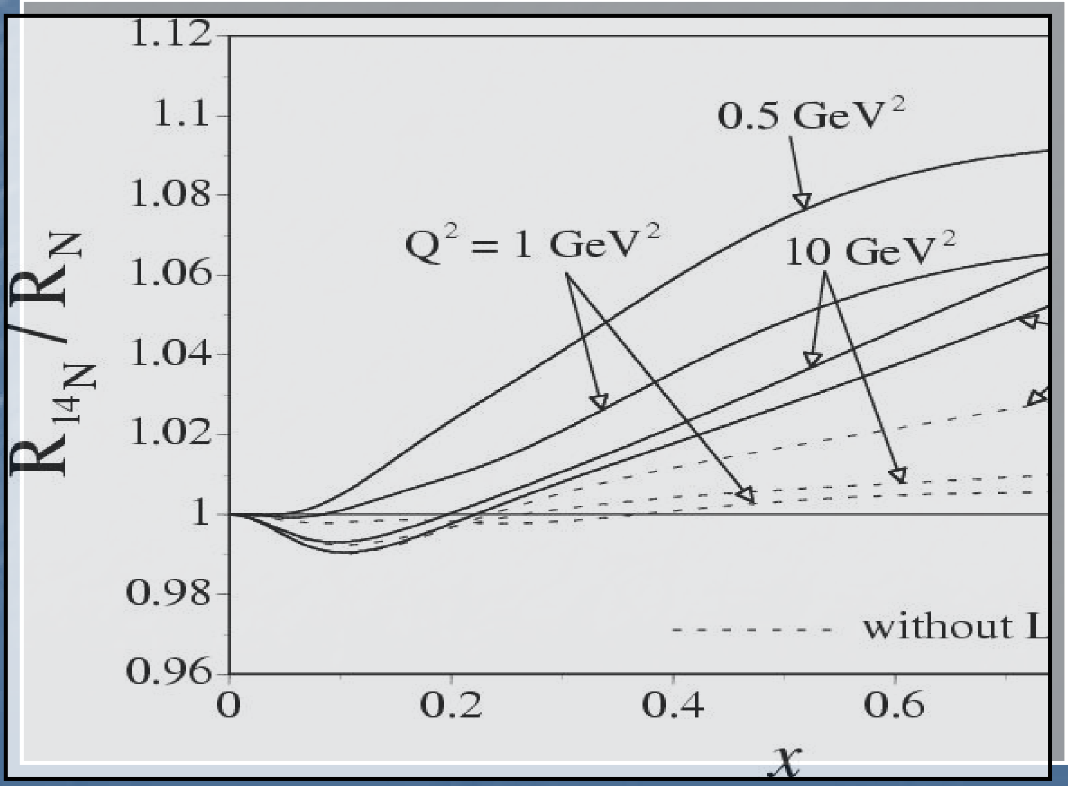
New results from Hermes Experiment



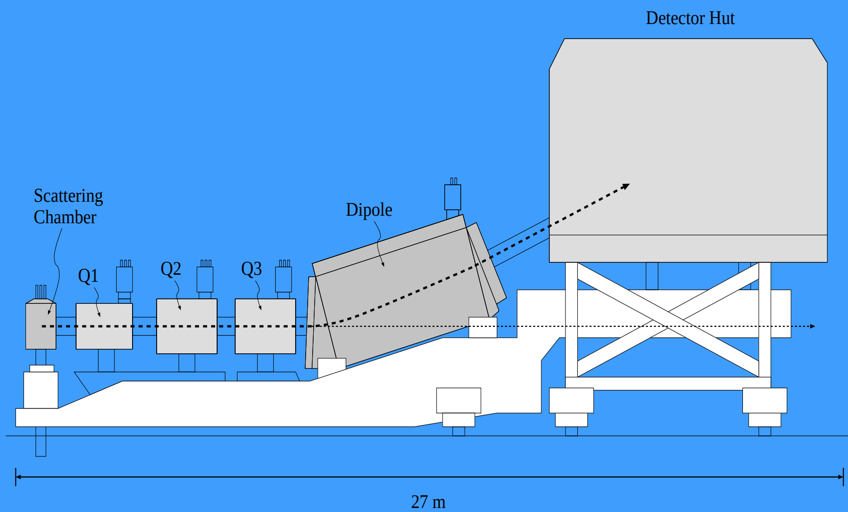


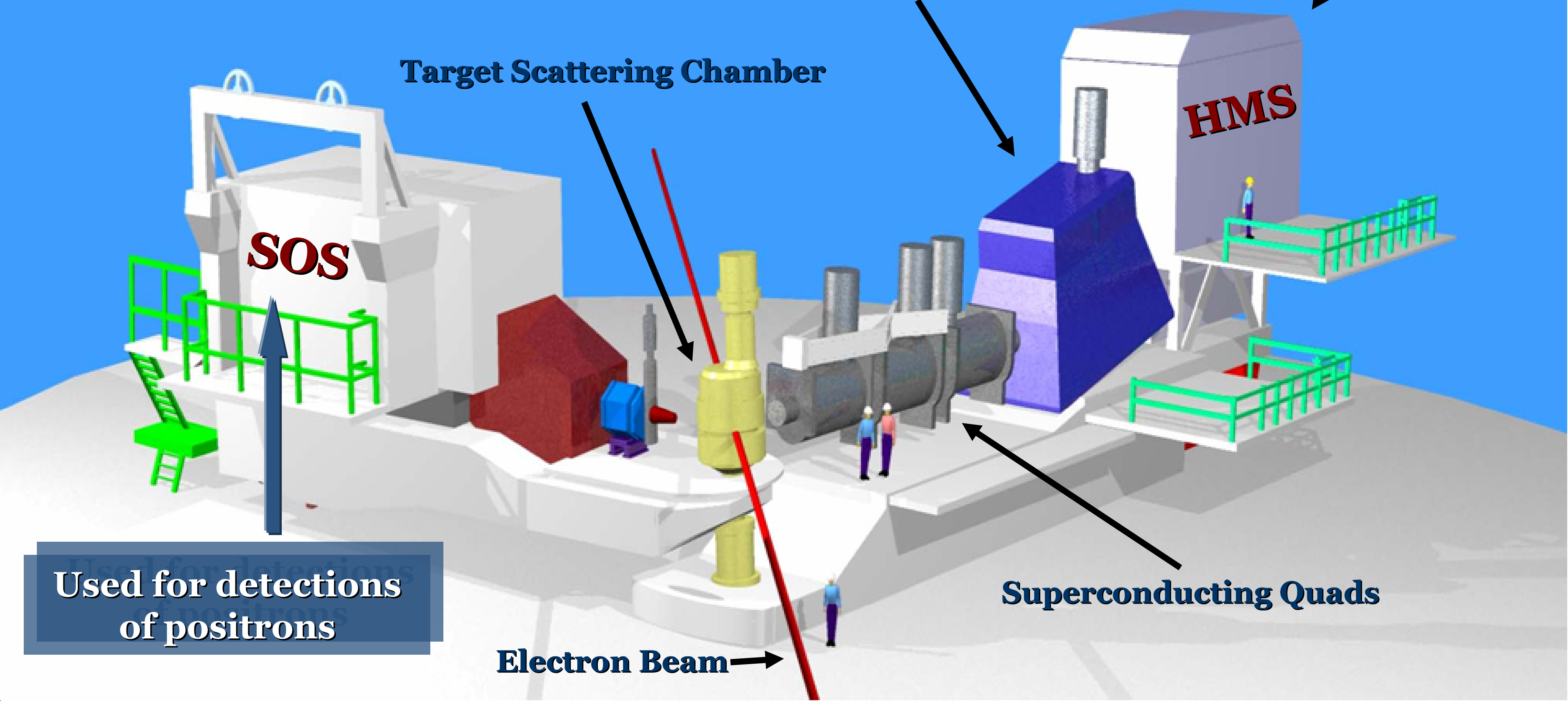
Nuclear Effects in F_2 and R

Alternatively, it has been shown that an A-dependence of $R(x,Q^2)$ may exist at high values of x and low values of Q^2 due to a mixture of the transverse and longitudinal structure functions. The transverse structure function for a nucleus is described not only by the transverse one for the nucleon but also by the longitudinal one with the admixture coefficient . The mixing arises from the fact that the nucleon momentum direction is not necessary along the virtual photon direction. Thus, the motion of the nucleon perpendicular to the direction of the virtual photon gives rise to a mixture of longitudinal and transverse structure functions in the nucleus.

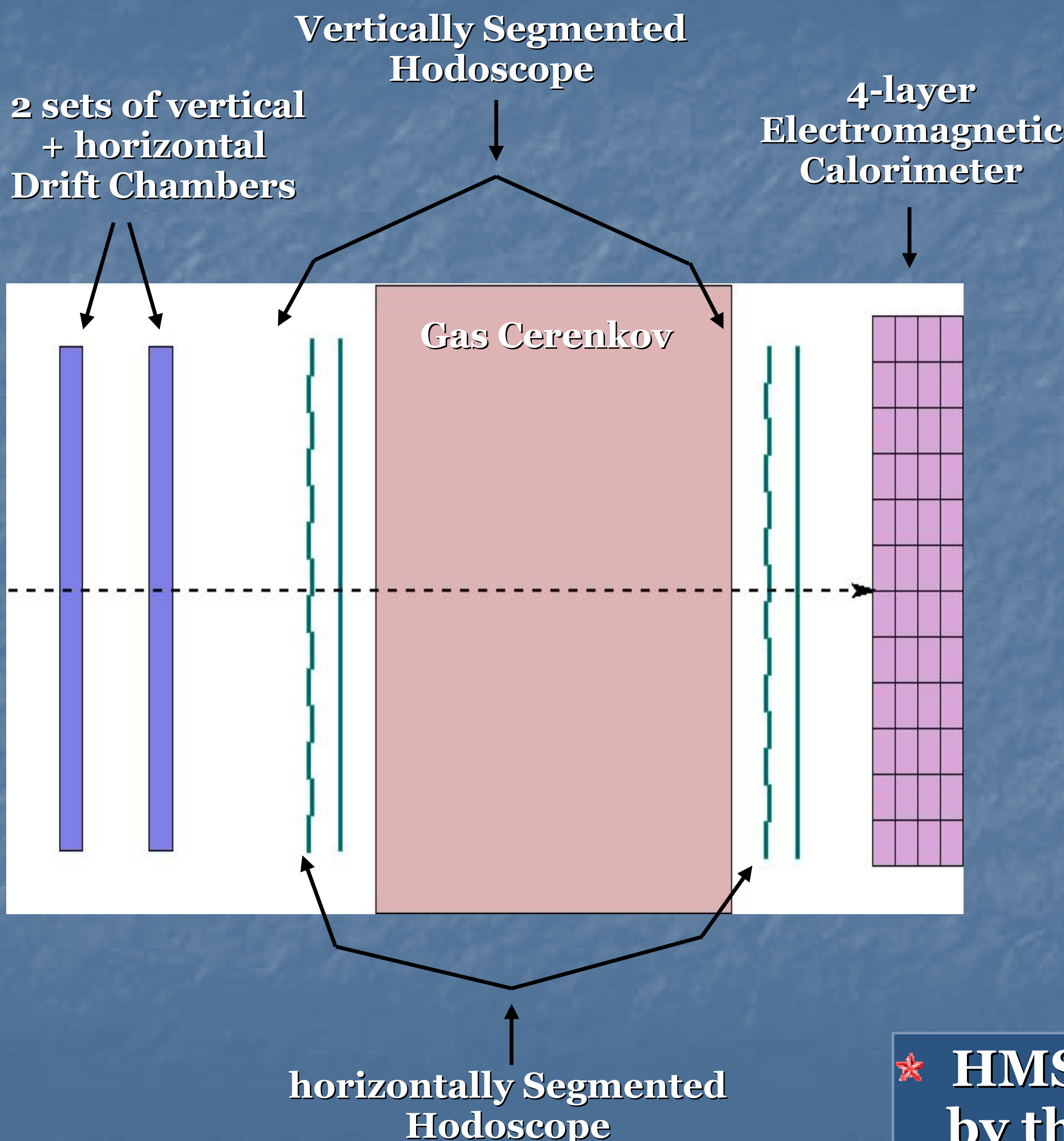


Jlab Hall C


Detector Hut
Scattering Chamber
Dipole
Q1
Q2
Q3
27 m


Used for detection of electrons
Shielded Detector Hut
Superconducting Dipole
Target Scattering Chamber
HMS
SOS
Used for detections of positrons
Electron Beam
Superconducting Quads

HMS Spectrometer

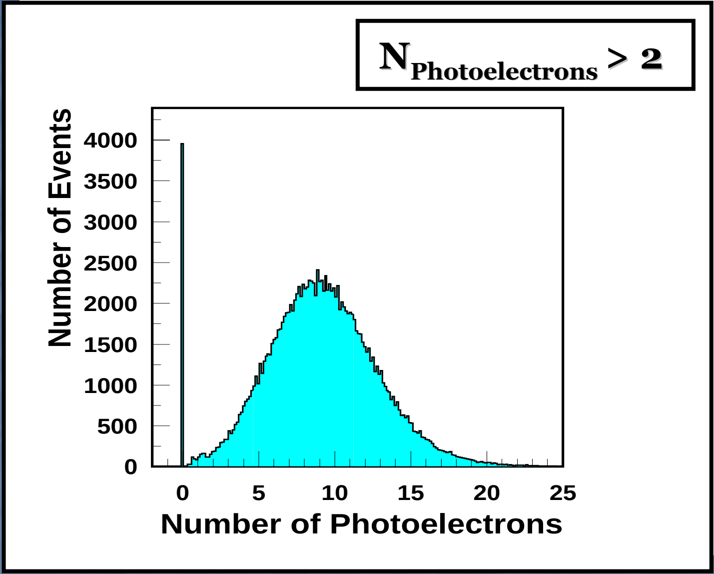


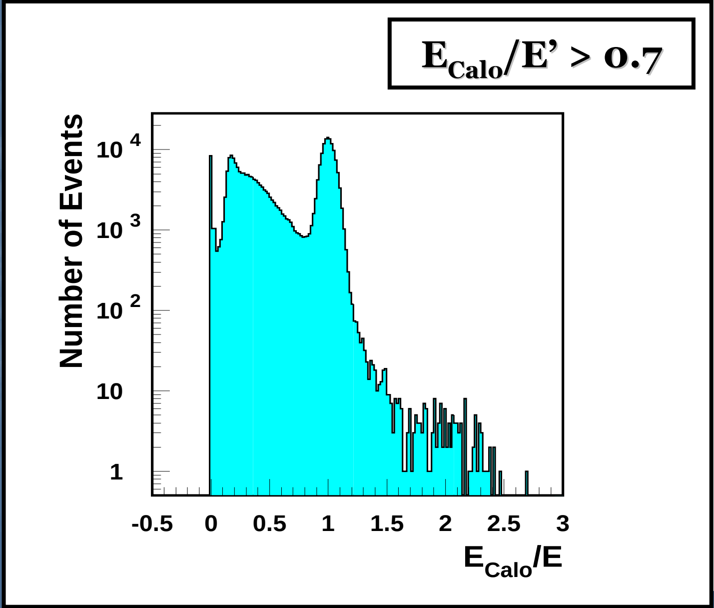
HMS Properties (pt-pt tune)	
Kinematic Range:	
Momentum:	0.5 – 7.5 GeV/c
Angular:	10.5^{o} - 80^{o}
Acceptance:	
Ω:	~6.5 msr
Dp/p:	+/-9%
Resolution:	
Dp/p:	< 0.1 %
Θ:	~ 1 mrad

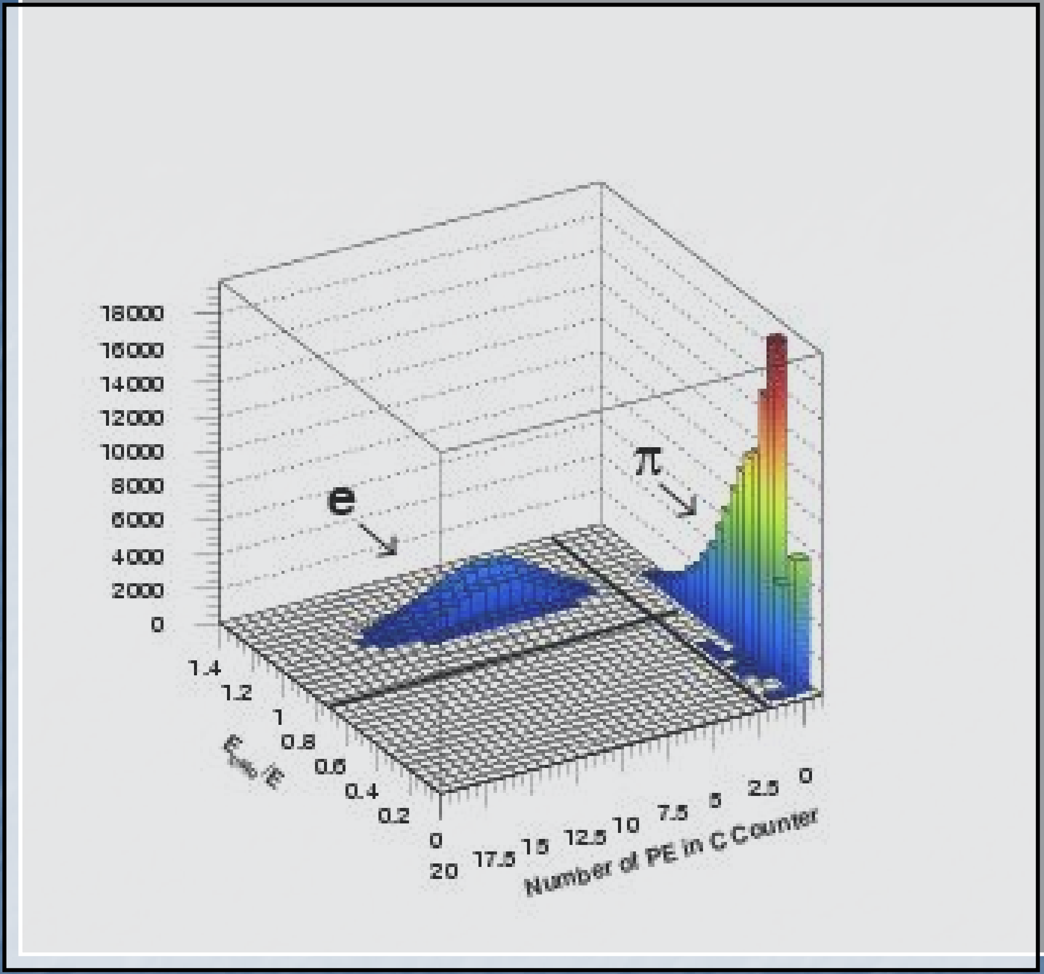
Cer + Cal provide π rejection factor ~ 10000/1 at 1 GeV

- HMS Acceptance is dominated by the octagonal collimator!

Particle Identification

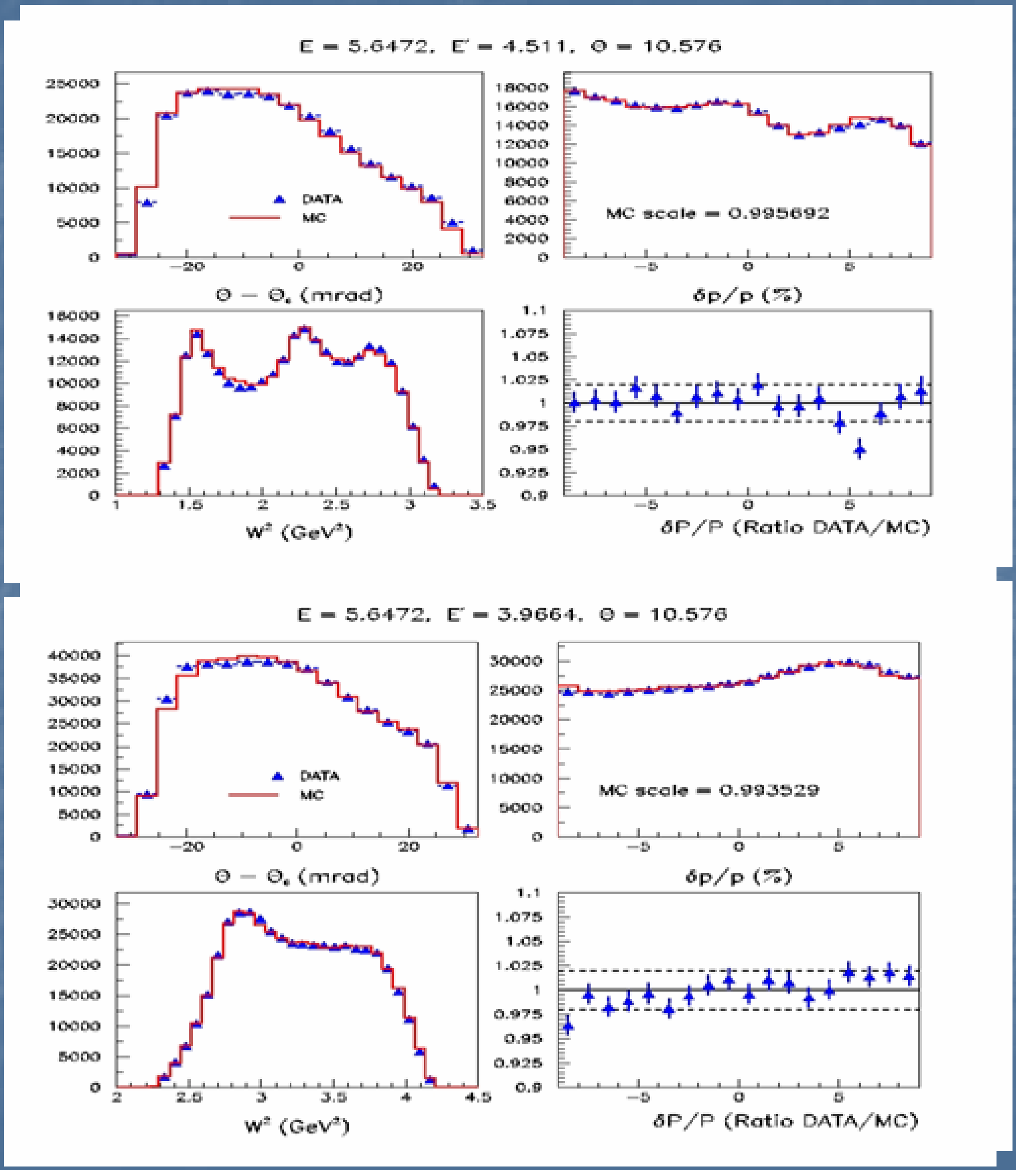






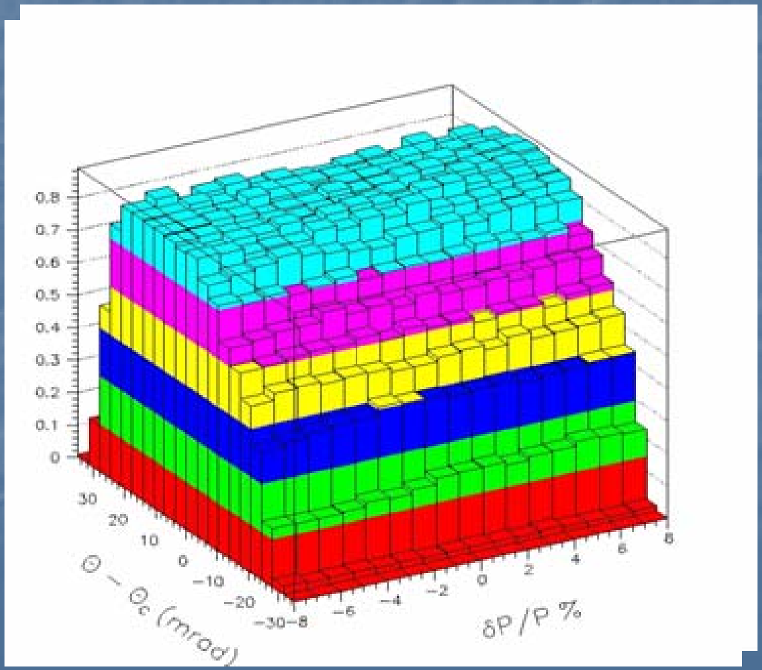
Subsystem	e^- Efficiency	Uncertainty
Cerenkov	> 99%	0.2%
Calorimeter	96.5 – 99.5%	0.3%
Tracking	90 – 98%	0.3%

HMS Monte-Carlo



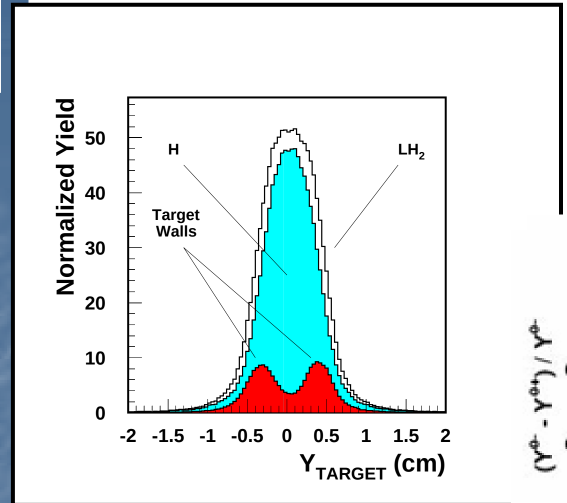
Comparison of MC to E99-118 data using E94-110 resonance region model as an event generator.

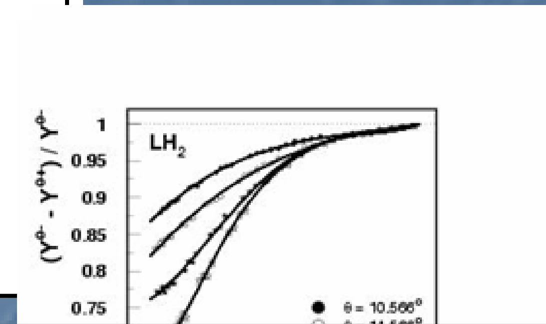
Excellent agreement between different experiments! Acceptance is determined to < 1% pt-pt in the kinematics.



Analysis Methodology

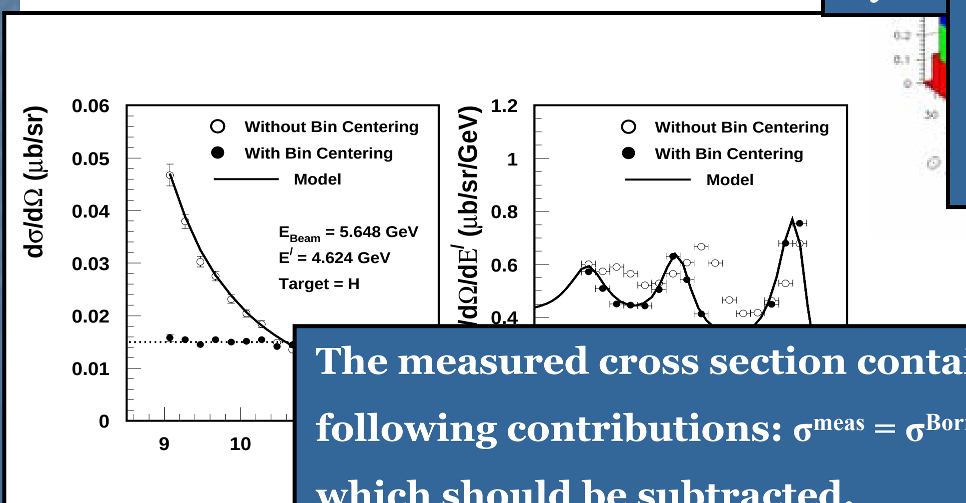
- Bin efficiency corrected e- yield in $\delta p/p$- Θ ($\delta p/p$ = +/-8%, $\Delta\Theta$ = +/-35 mrad)
- Subtract empty target background bin-by-bin.
- Subtract charge symmetric e- yield bin-by-bin.
- Apply acceptance correction for each δ - Θ bin.
- Apply radiative corrections bin-by-bin.
- Apply Θ bin-centering correction and average over Θ for each δ bin.

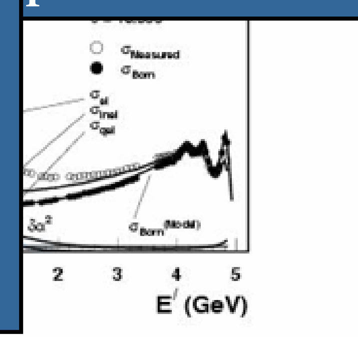




During the data taking on a cryotarget some of the incoming electrons scatter on the aluminium walls and create a background, which should be subtr… hydr…

In the detected electron spectrum there is an unwanted real electron background coming from γ and π^0 particles produced in the target. The… s, which can pro… pairs.

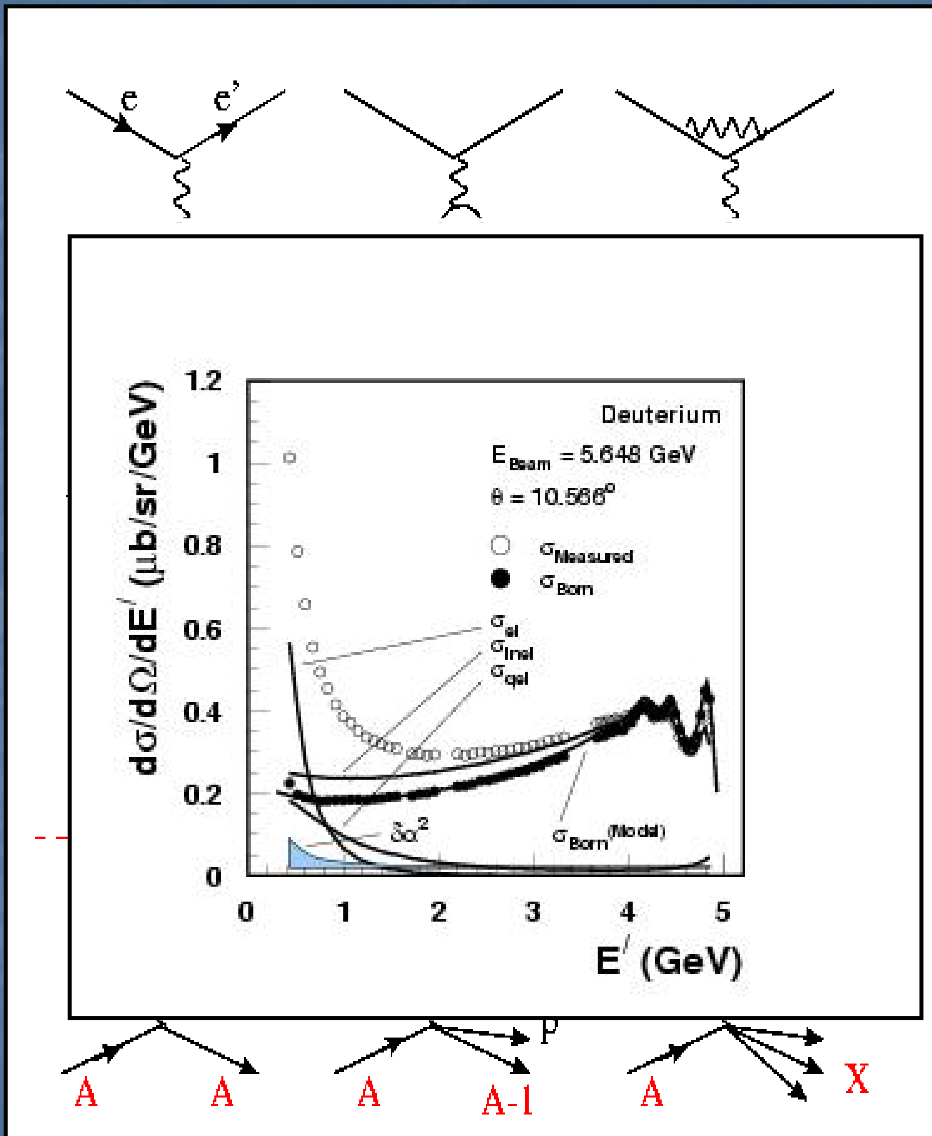




The measured cross section contains following contributions: $\sigma^{meas} = \sigma^{Born} + \sigma$… which should be subtracted.

The spectrometer acceptance (HMS) in θ is about 1.8 %. Therefore, in order to determine the cross section at the central angle, a so-called bin centering correction must be applied.

Radiative Corrections



$$\sigma^{Meas} = \sigma^{Born} + \sigma^{el} + \sigma^{qel} + \sigma^{inel}$$

$$\sigma^{Born} = \eta \times \sigma^{Meas}$$

$$\eta = \frac{\sigma^{Model}_{Born}}{\sigma^{el} + \sigma^{qel} + \sigma^{inel}}$$

$$\sigma_{Born} = \left(\sigma_{Meas} - \sigma_{El} - \sigma_{Qel}\right)\frac{\sigma^{Model}_{Born}}{\sigma_{Inel}}$$

Bardin: (TERAD) Only calculates Internal Radiative Corrections (Includes 2-photon Corrections)

Mo,Tsai: calculates Internal & External Radiative Corrections

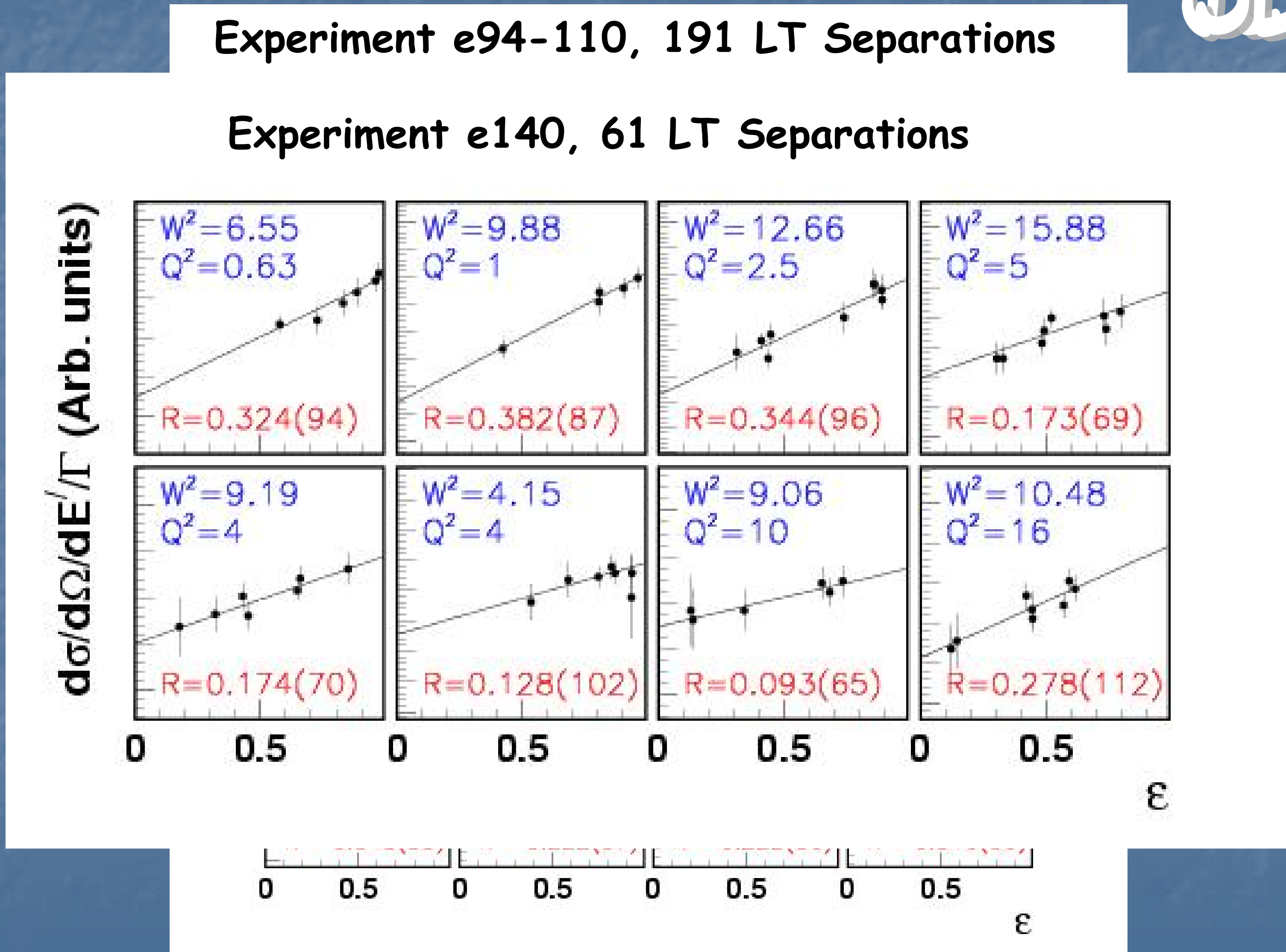
$$\sigma_{Int} = \sigma^{Int}_{El} + \sigma^{Int}_{Qel} + \sigma^{Int}_{Inel}$$

$$\sigma_{Ext} = \sigma^{Ext}_{El} + \sigma^{Ext}_{Qel} + \sigma^{Ext}_{Inel}$$

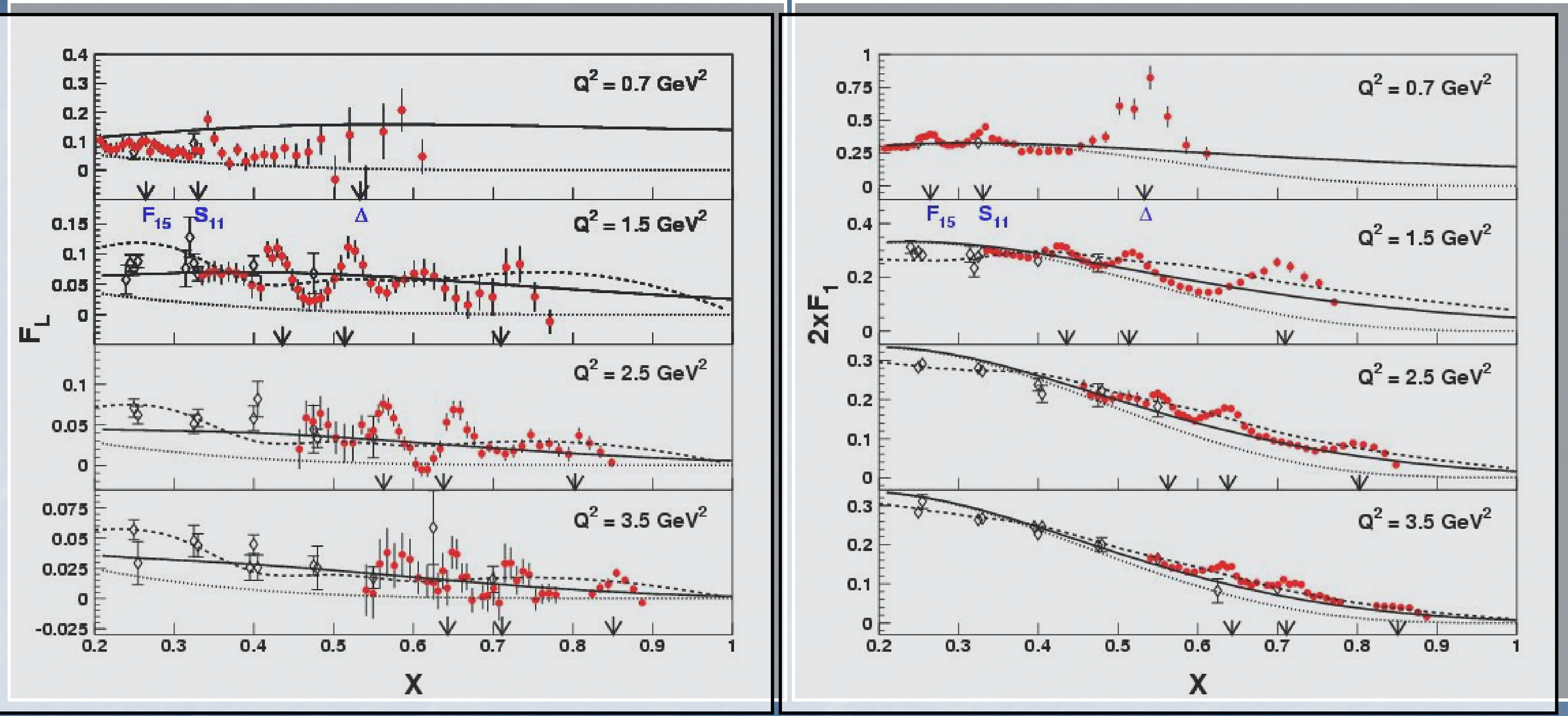
$$\sigma_{Born} = \sigma_{Meas} - \sigma^{Int}_{Bardin}\left(\frac{\sigma^{Int} + \sigma^{Ext}}{\sigma^{Int}}\right)_{Mo,Tsai}$$

Example Rosenbluth Separations

SLAC

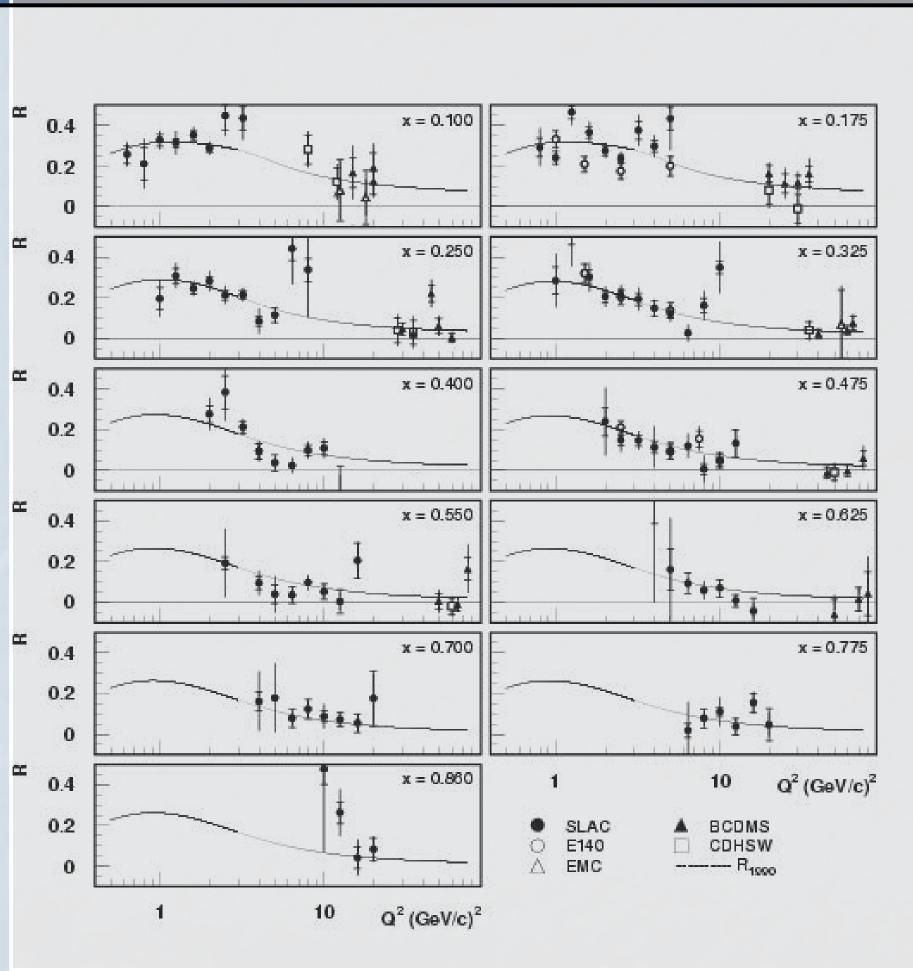


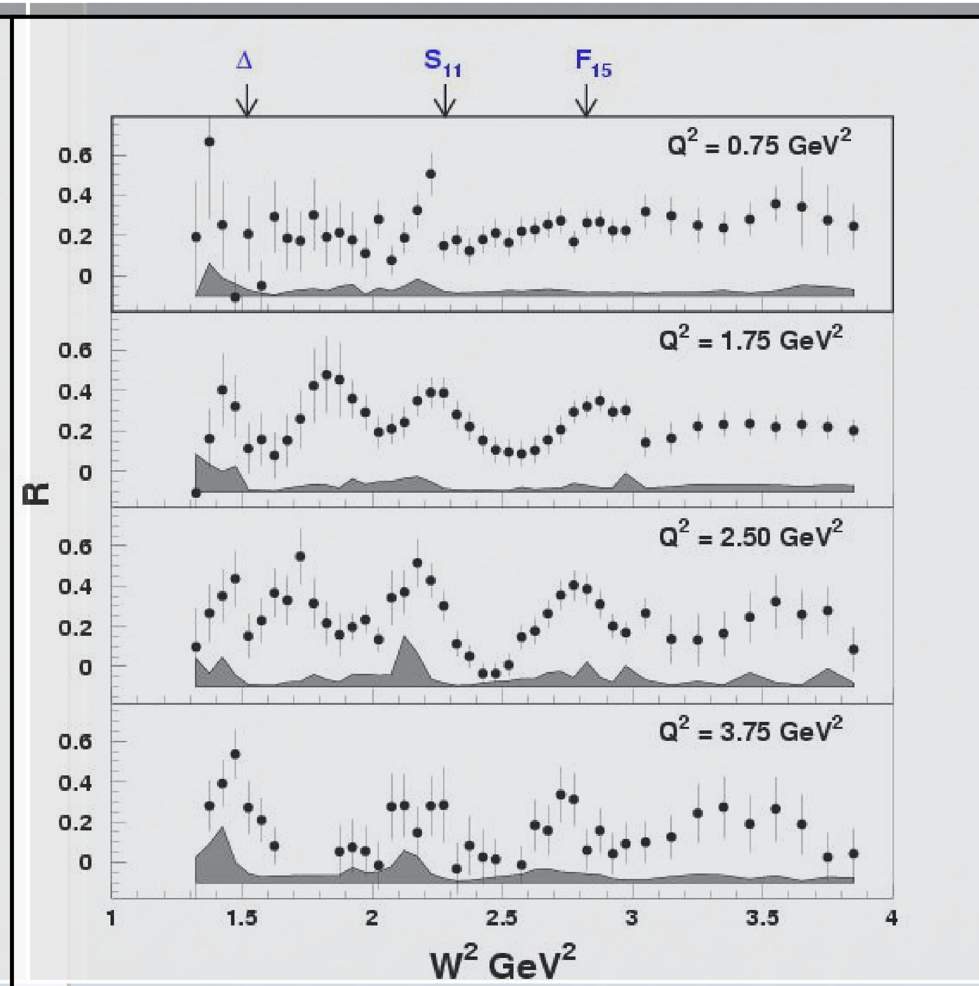
Results from e94-110 (F_1, F_L)



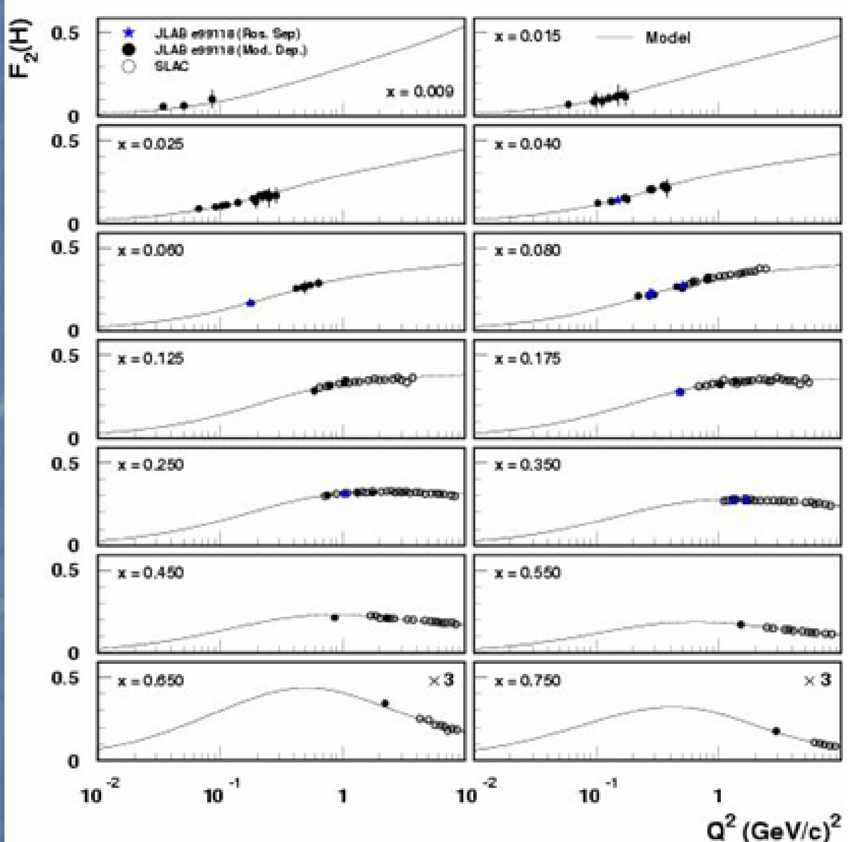
The solid curve is calculated from R1998 fit of R and the Whitlow's F_2 fit. The dotted curve is the MRST (NNLO) fit. The dashed curve is the MRST (NNLO) fit with the target mass corrections.

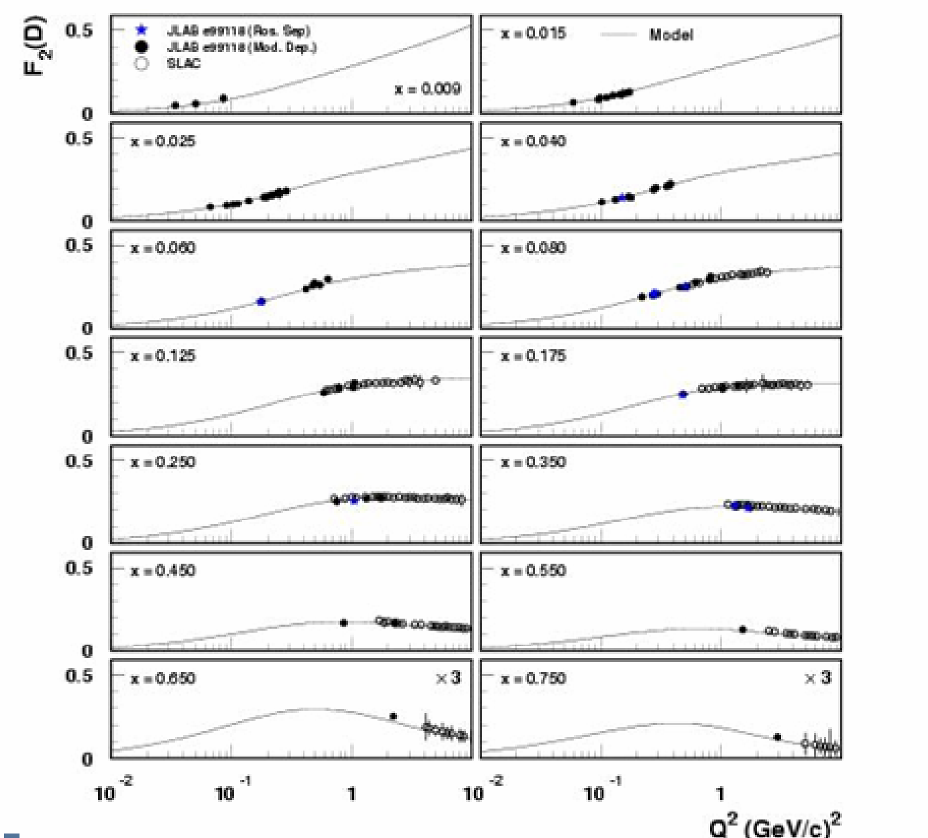
Results from e94-110 (R)



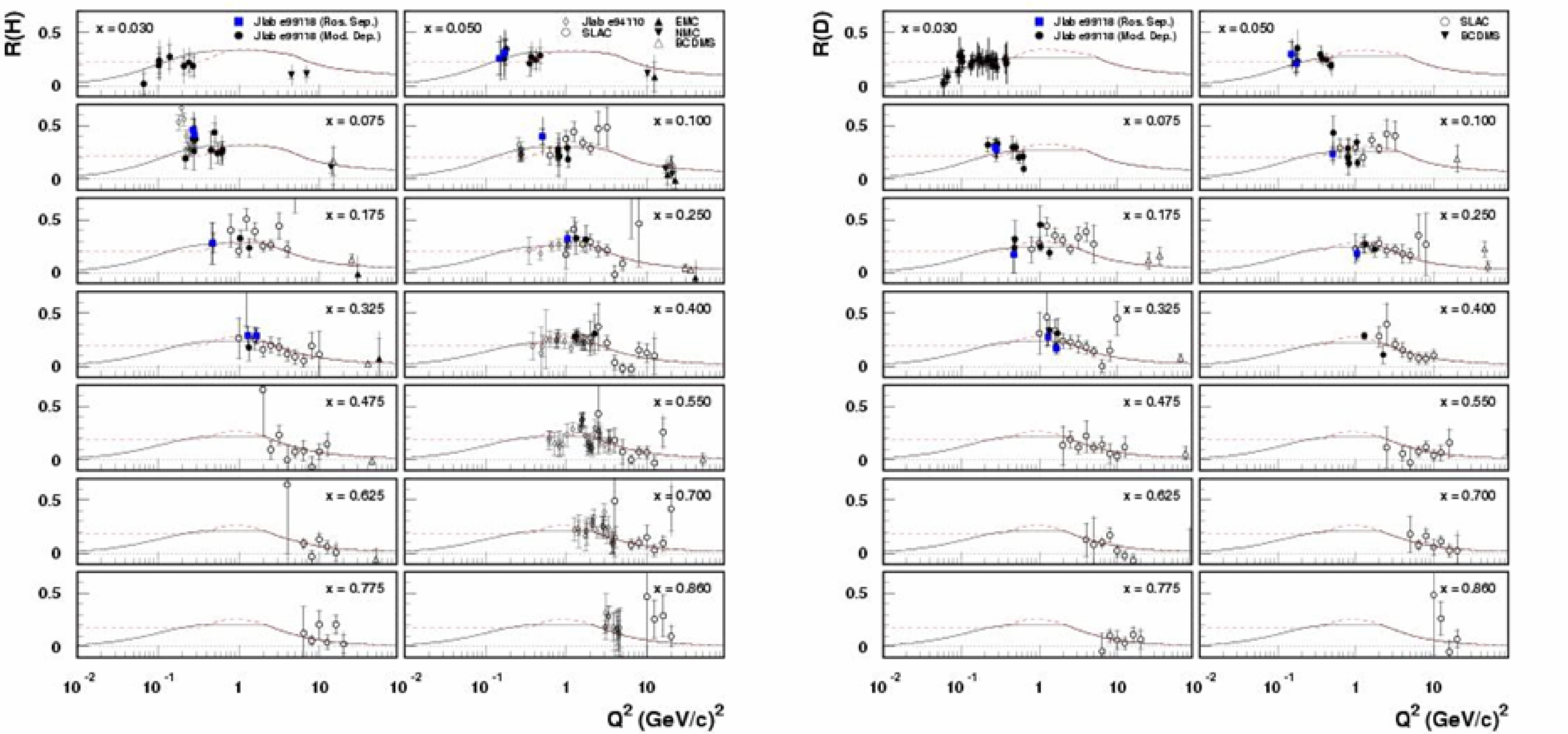


Results from e99-118 (F_2 for H & D)

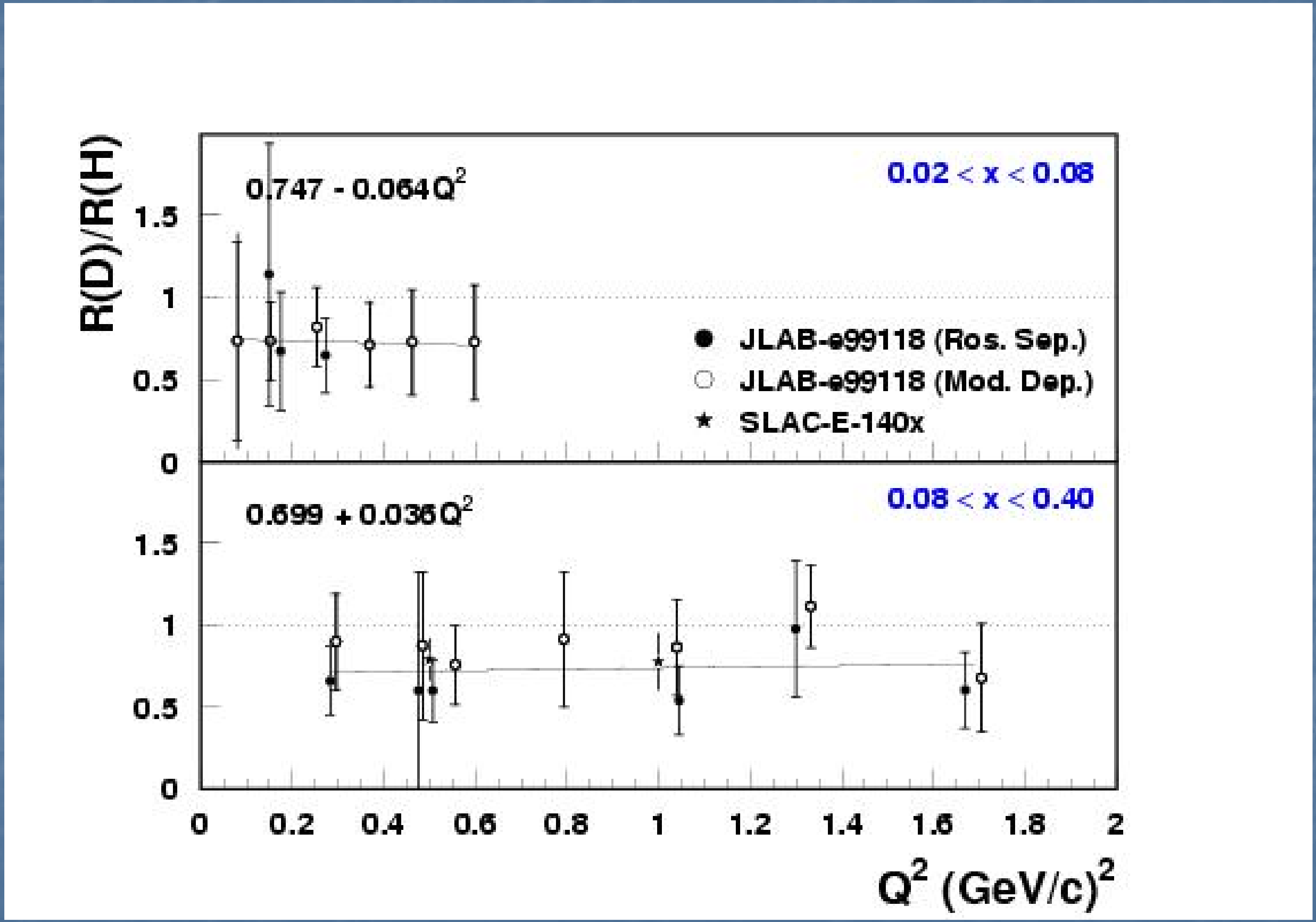




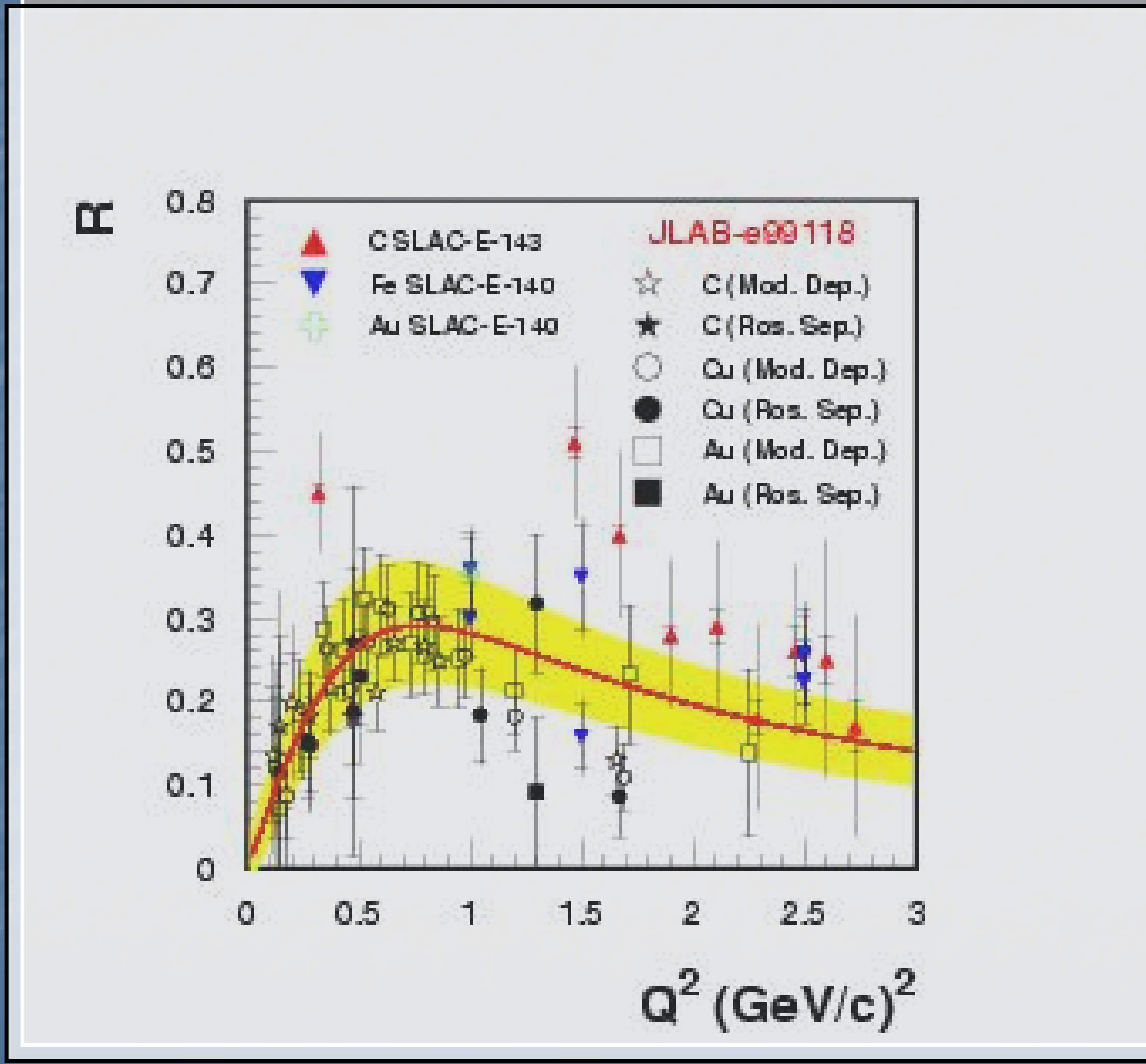
Results from e99-118 ($R = \sigma_L/\sigma_T$)



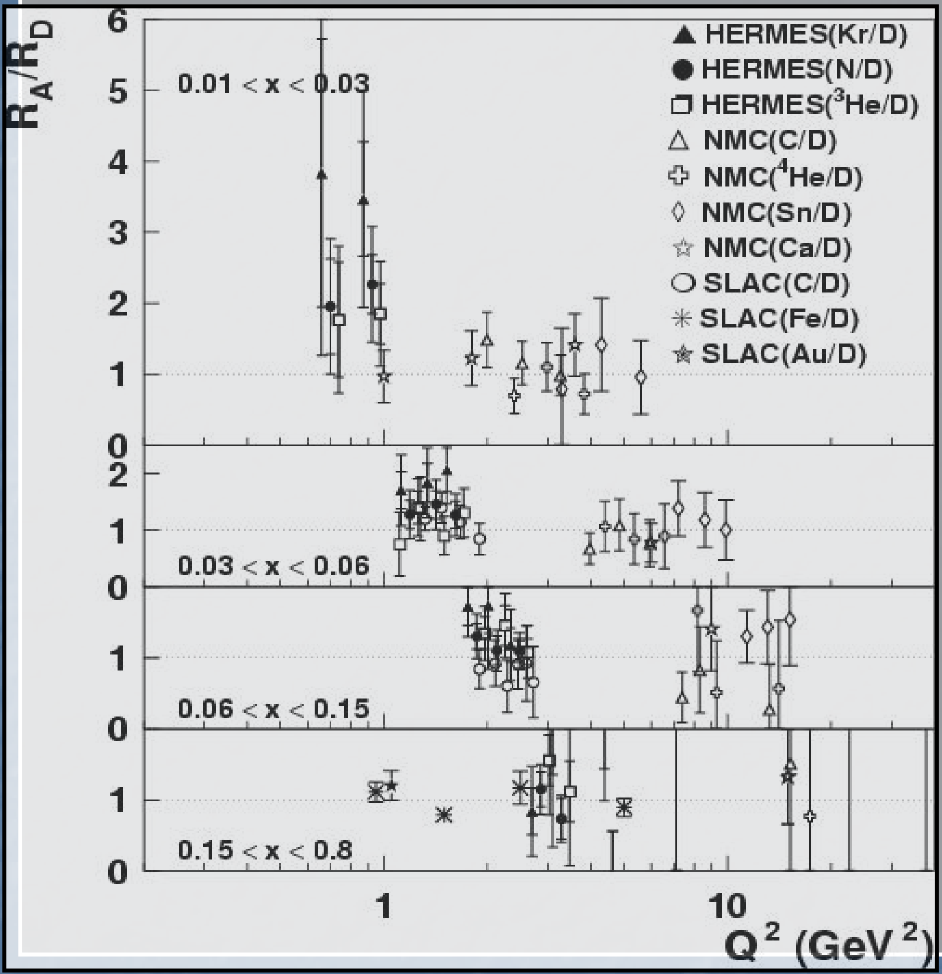
Results from e99-118 (R^D/R^H)

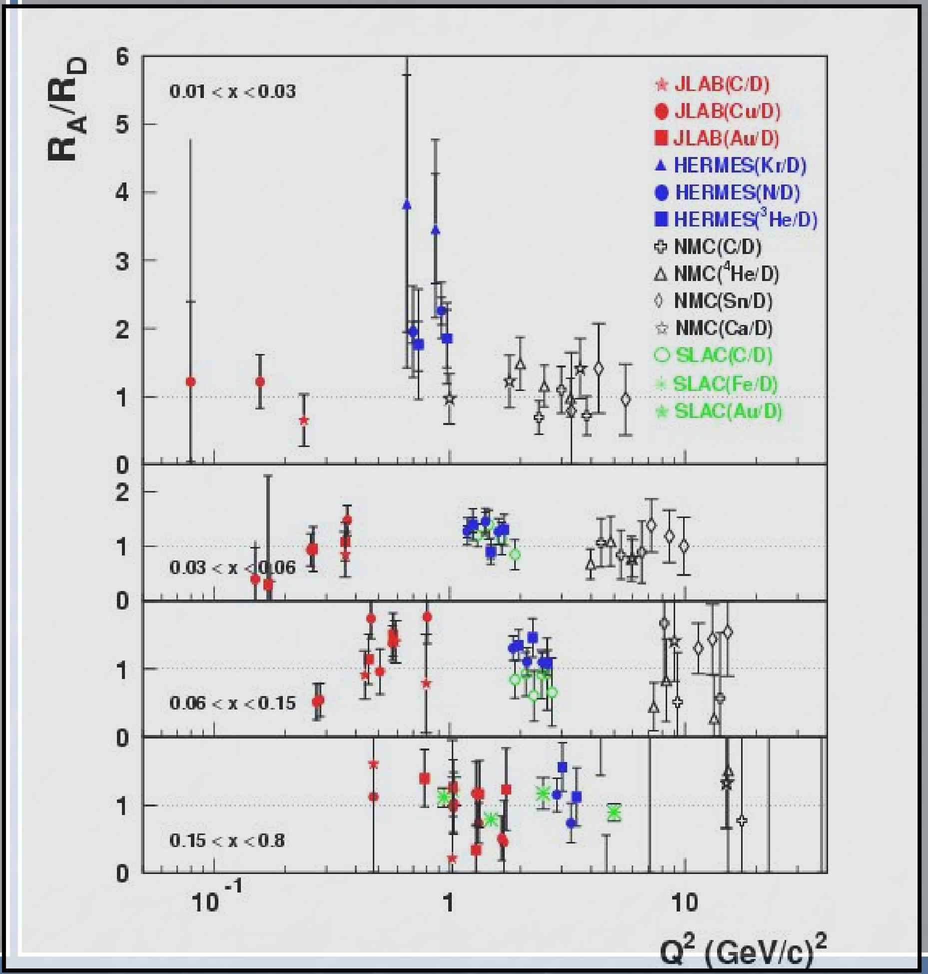


Results from e99-118 (R^A)

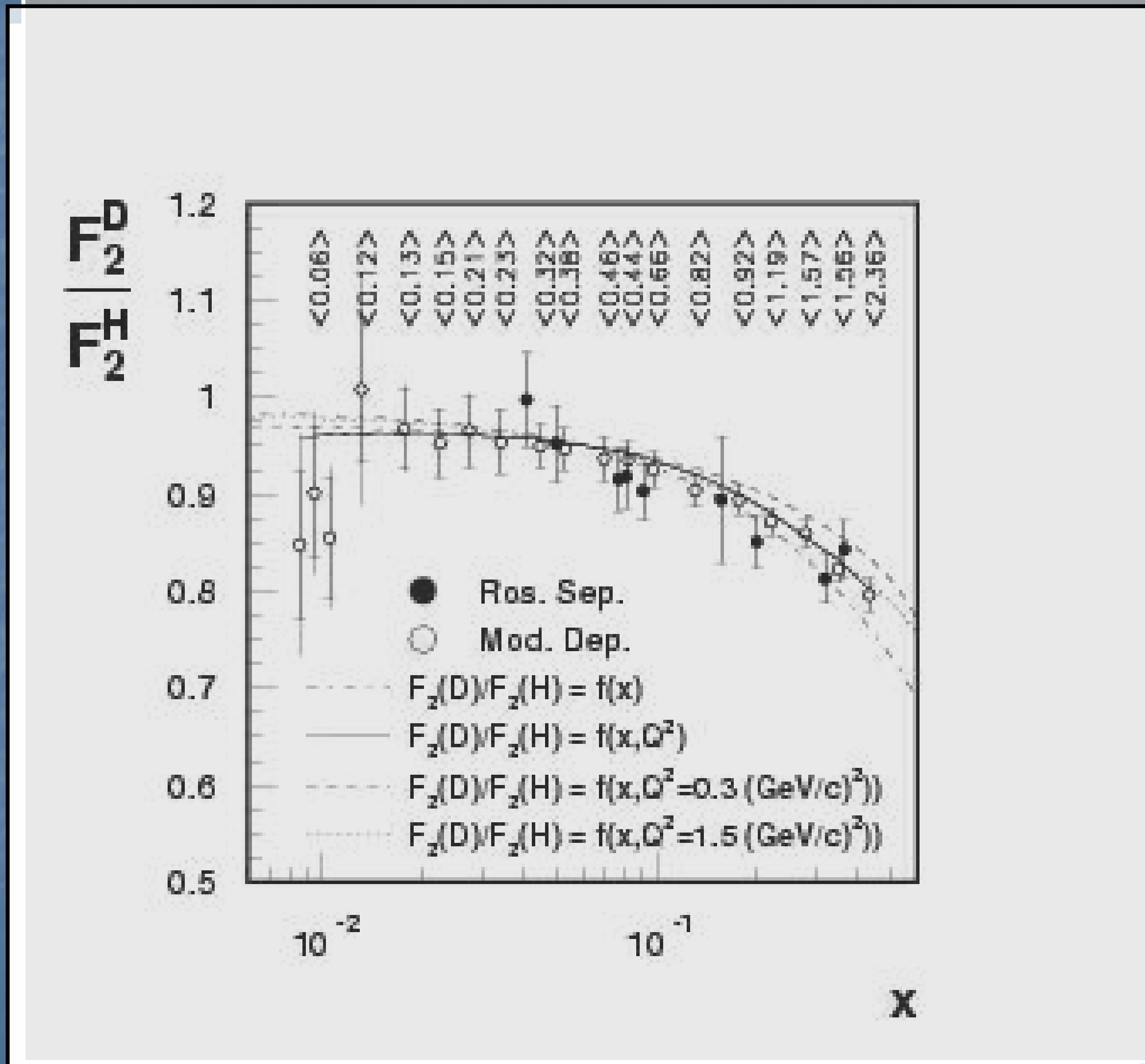


Results from e99-118 (R^A/R^D)

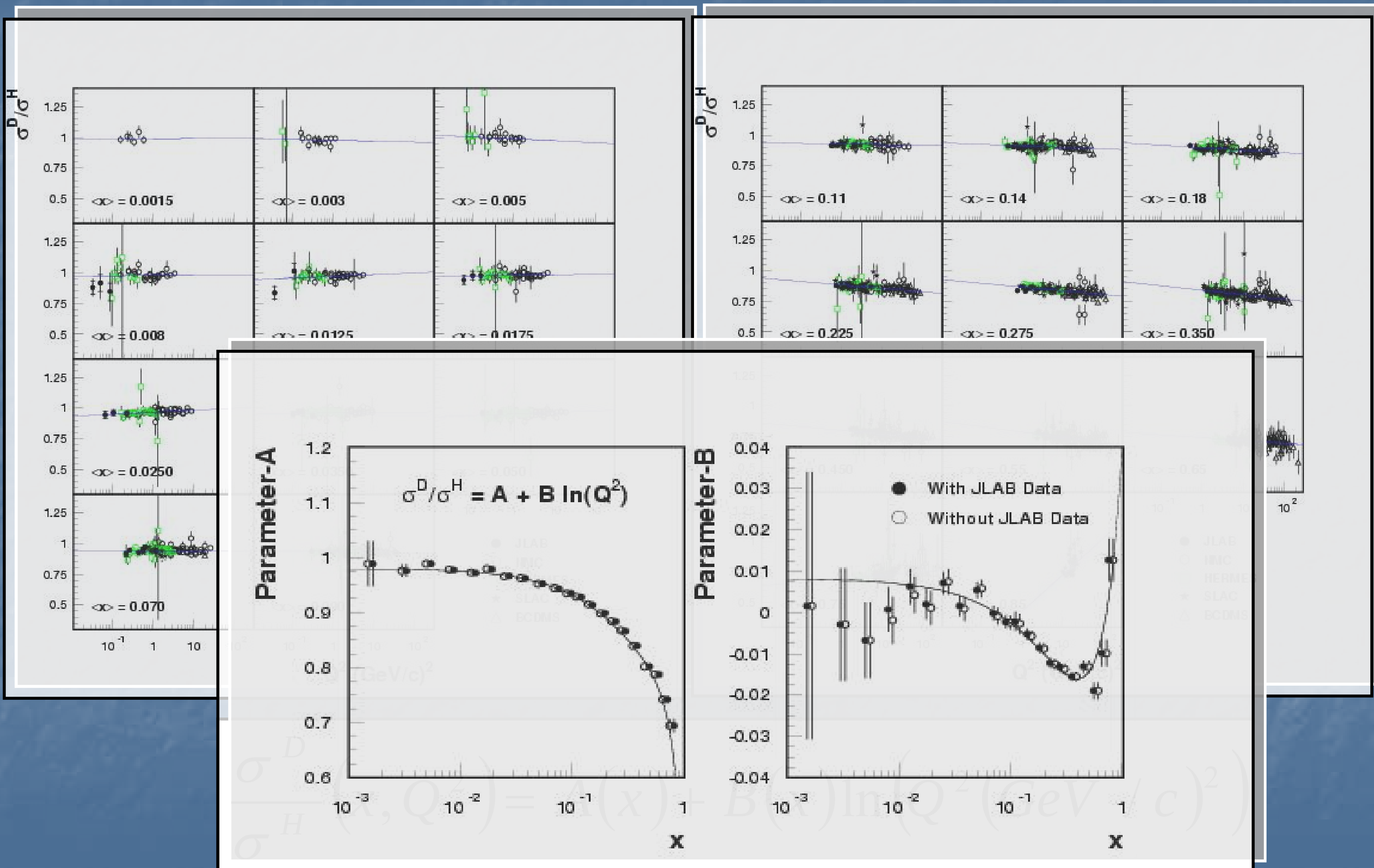




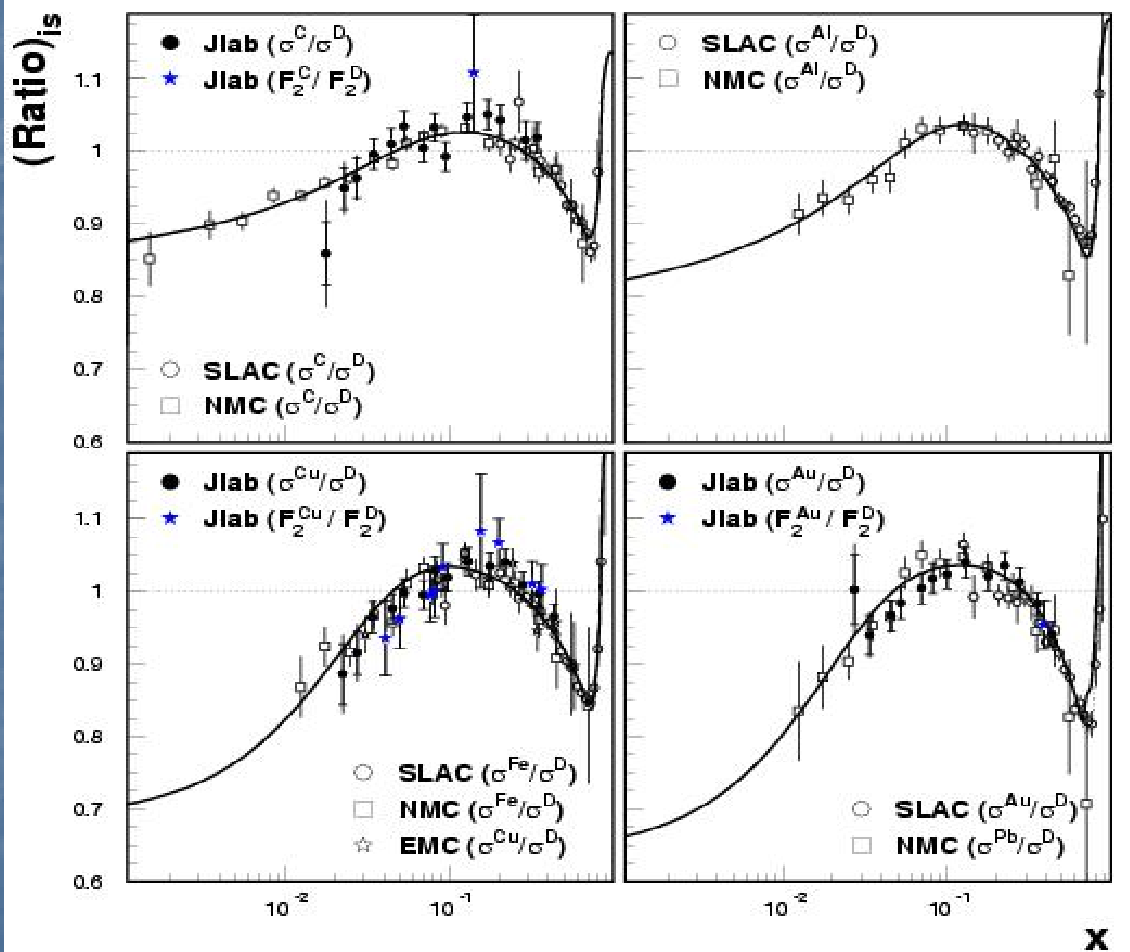
Results from e99-118 (σ^D/σ^H, or $F_2(D)/F_2(H)$)



Results from e99-118 (σ^D/σ^H, Q^2 dependence)



Results from e99-118 (σ^A/σ^D)



Summary .....

Analysis of the experiment e99-118 is finished for Hydrogen and Deuterium Targets. R Does Not go to zero (as Q^2 goes to zero), only at very low x there is a hint that R goes to zero. Analysis indicates that possibly $R^H > R^D$.

The ratios R^A/R^D from the present experiment, as well as the ratios from other experiments, indicate that $R^A/R^D = 1$. Thus, no A-dependence of R (x, Q^2) was observed, neither in the experiments that were done at high values of Q^2 ($Q^2 > 1$ (GeV/c)^2), nor in the e99-118 experiment, which was done at low values of Q^2.

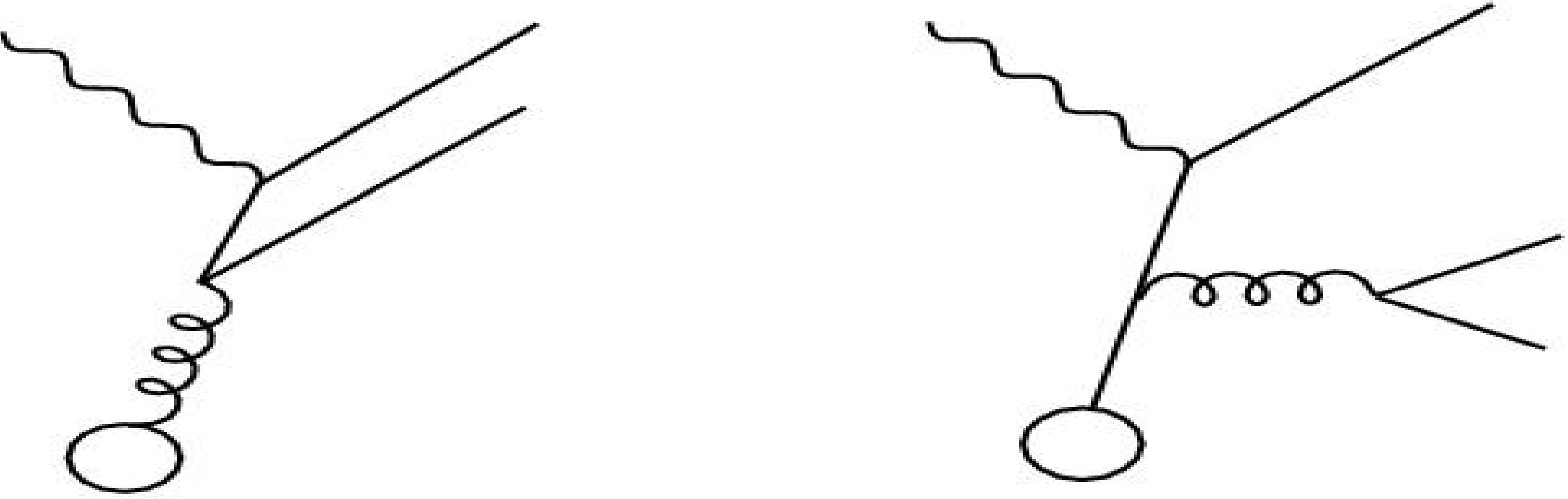
The x dependence was studied for the ratio of the cross sections σ^D/σ^H. The x dependence of the ratio σ^D/σ^H from the present experiment was compared with the parametrization of F_2^D/F_2^H of the world data. Since all previous data indicated that $R^H = R^D$ within the (large) error bars, or were taken at high ε, for those data the ratio of the cross sections σ^D/σ^H was equal to the ratio of the structure functions F_2^D/F_2^H. The data from the present experiment indicated that there was a difference between R^H and R^D . In order to account for the influence of the different R^H and R^D on the ratio σ^D/σ^H, the data from the present experiment were corrected for the difference between R^H and R^D. The corrected ratio was in better agreement with the parametrization then the uncorrected ratio.

The ratio of the structure functions F_2^D/F_2^H was determined via the Rosenbluth separation technique were compared as a function of x with the world data parametrization. The comparison showed a reasonable agreement with the data from other experiments.

The Q^2 dependence of the corrected ratio σ^D/σ^H from the present experiment was compared with the world data and the parametrization of F_2^D/F_2^H. The data from the present experiment were in excellent agreement with the parametrization and had relatively small error bars.

a) b)

Leading order (LO) QCD corrections (a,b,c). Gluon bremsstrahlung diagram before (a) and after interaction (b). Coupling of virtual photon and gluon via quark-antiquark production (c). Example of the next-to-leading (NLO) order correction (d).



c) d)